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Construction Management and Foundation Designs for WPI Athletic Rooftop Parking Garage

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A Major Qualifying Project Report
Submitted to the Faculty of Worcester Polytechnic Institute
In partial fulfillment of the requirements for the
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Submitted To:

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Abstract

This project tracks the schedule and cost of the new WPI athletic rooftop parking structure as observed during construction and develops a 5D model (3D plus time and cost dimensions) of this process using Building Information Modeling tools and techniques. This project also designs a foundation system that includes a combination of deep and shallow structural foundations for the parking garage with an athletic rooftop.

Capstone Design Statement

The Capstone Design Experience is a requirement by the Civil and Environmental Engineering department at Worcester Polytechnic Institute (WPI), for all Major Qualifying Projects (MQPs). This experience helps students to be prepared for engineering practice based on the knowledge and skills acquired in earlier course work and incorporating engineering standards and realistic constraints.

In order to meet this requirement this MQP has been developed within the global context of WPI parking concerns limited by the current land resources available which was accomplished through the construction of a new structure with a combined use of parking garage and a roof-top athletic field. This MQP mainly focuses on the design of a foundation system that given the actual soil conditions includes a combination of deep and shallow foundations system for this building and it also uses Building Information Modeling for analysis of construction planning and management.

The soil report was carefully analyzed along with other design materials to estimate the values for live loads and dead loads from the structure which would be acting on the foundations. According to the type of soil material the foundation area was separated into different zones. The zone with the bedrock located near the surface was determined to have a soil bearing capacity allowable for shallow foundation. The zone with bedrock at much deeper locations was proposed a Pressure-Injected-Footing as the soil conditions were poor. The proposed design was then compared to the original foundation plan to see the variations caused by more in-depth information.

Economic and Constructability considerations: Project Management skills are used in this project, to outline the construction progress of the building. Using Autodesk Revit Structure and

Architecture software a 3D digital model of the facility was created; in conjunction with Microsoft Project schedule it is possible to visualize the activities with their corresponding gradual construction of the garage. This is often known as the 4-Dimensional model. A cost analysis was then added to the 4D model to create what is known as a 5D model. To better understand the overall management of the project, the students attended some of the weekly meetings that took place among the owner, the designer and the builder.

Acknowledgements

We would like to thank individuals who helped in the succession on this Major Qualifying Project. Without your help and guidance, this project would not have been possible.

WPI Project Advisors

Dr. Guillermo Salazar

Dr. Mingjiang Tao

WPI Representatives

Jeffery Solomon, Executive Vice President and Chief Financial Officer

Dana Harmon, Director of Athletics

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Dennis Murphy, Project Scheduler

Cardinal Construction Services

Brent Arthaud, President

Symmes Maini & McKee Associates

Michael Andrews, Project Architect

Authorship Page

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1.0 Introduction

Universities and businesses alike are often rated on how they treat their customers and staff. The majors and activities that a university offer as well as the student-to-faculty ratio and diversity help determine a university's rating (Morse, 2012). In regards to businesses, both salaries and incentives are all factors that contribute to a company's ranking. Although the main goal of a university is to produce intelligent graduates that will make a positive contribution to society, other elements such as athletics, extracurricular opportunities and the supporting infrastructure such as buildings, parking and athletic fields contribute to the overall success of the university. Being able to provide parking for students, visitors, and employees is a major benefit and a lack thereof can be a major detractor.

Parking is a very important part of the community, especially in daily business life. For staff, easy to find parking can help reduce the time wasted looking for parking, and can positively influence the employee's mood. For visitors and potential students, unfavorable parking conditions have the potential to start off the visit negatively, which may impact their outlook on the rest of their visit.

According to an interview with Janet Richardson, VP of Student Affairs & Campus Life, parking at WPI has been a serious and well known problem across campus for an extended amount of time (Grasso & Urdaneta, 2012). The quantity of parking spaces available at WPI is not sufficient for the amount of faculty and students who require a car on campus.

Dana Harmon, the Director of Physical education at WPI explained that with the increasing population at WPI, it is safe to assume that the need for parking will only increase (Grasso &

Urdaneta, 2012). The amount of students, faculty, administrators, other employees and visitors at WPI contribute to this problem. WPI has recognized this need for additional parking and has evaluated a surplus of options to try to solve it.

Janet Richardson explained that after careful consideration of a multitude of options to expand parking, the project combining a parking garage and athletic field was developed. The best overall option was considered to create a parking garage in the northwest corner of the WPI campus, between the First Baptist church and football field. This space was originally used as athletic fields for the baseball and softball teams. To maximize the given space, this new $20 million, 534 car parking garage contains a synthetic turf rooftop that consists of a softball and soccer field as well as other athletic facilities with bleachers to sit 300 spectators. There will be fencing topped with netting along with field lighting will surround the perimeter of the fields. This parking structure will also contain a concession stand with locker rooms and storage facilities. The building is expected to be energy efficient and be built with recyclable materials. (Worcester Polytechnic Institute, 2012)

When looking at specifics for the field, the Trustees looked at a few major options. A one story underground parking garage was considered, but according to the project's architect, this would require extensive ventilation and would be an extremely costly investment. A second option was to create a one story parking garage, but designing the structure for a future addition of a second level when current parking later exceeds its limits. This option was also rejected because there was no way to foresee future building codes which could cause unnecessary design loads and also added to the cost of the facility. A third option was to build a second story to the parking garage now, but WPI trustees considered that playing at the higher altitudes would be challenging and the additional height would be considered an eye sore. Therefore, the only cost effective, logical option was to construct a one story aboveground parking structure with the rooftop fields. This was considered both cost effective and easily accessible.

One increasingly accepted and convenient software tool that has been used throughout this project is Building Information Modeling software or BIM. This software allows the architect or construction manager to create a 3D computer animation of the construction project. This can be extremely useful when discussing different options that may come into play during a construction project. BIM programs such as Autodesk Revit and Architecture allow the owner to visualize the different color schemes or room orientations before completing construction to make quick accurate decisions regarding ordered materials or the project designs. This allows the owner to see changes to the project in a 3D computer model before the project is built, so they have the option to see alternatives and make the best decision with minimal upfront costs

The foundation of the parking garage is unique. The soil beneath the proposed parking garage varies. Some areas of the plot hit bedrock close to the surface while other areas have a weak soil deep below the surface. The two main types of foundation footings are deep and shallow foundations. Deep foundations are needed for weaker soil bearing capacities while shallow footings are used to stronger soil bearing capacities. The combination of different soil bearing capacities beneath the proposed parking garage and athletic field caused the foundation to consist of a combination of deep and shallow foundations.

The main goals of this Major Qualifying Project (MQP) include tracking construction progress cost which is further analyzed by an earned value analysis, and creating of 5D Building Information Modeling showing 3D gradual progression of construction over time (4D) with its associated cumulative cost (5D). This MQP also focuses on designing an efficient foundation comprised of both deep and shallow foundation footings for the new parking garage with an athletic rooftop.

2.0 Project Management

According to Dr. Oberlender, a professional civil engineer, project management is defined as "the art and science of coordinating people, equipment, materials, money, and schedules to complete a specific project on time and within approved cost" (Oberlender, 2000). It is the responsibility of the project management team to keep the project within the given schedule and budget provided by the owner. The management team must focus on who does what when and how much it will cost to do so, as well as solve any problems that may rise throughout the project. The management team is also the main line of communications between all parties involved, including the: architect, structural engineer, subcontractors and the owner. (Oberlender, 2000).

2.1 Project Team

The project team for this parking garage consists of the owner, who hires an owner's representative, a contractor-led design-build group at risk consisting of a construction management firm who hires the architectural firm as well as all construction subcontractors to complete the necessary trades of work. The work breakdown can be seen in Figure 1.

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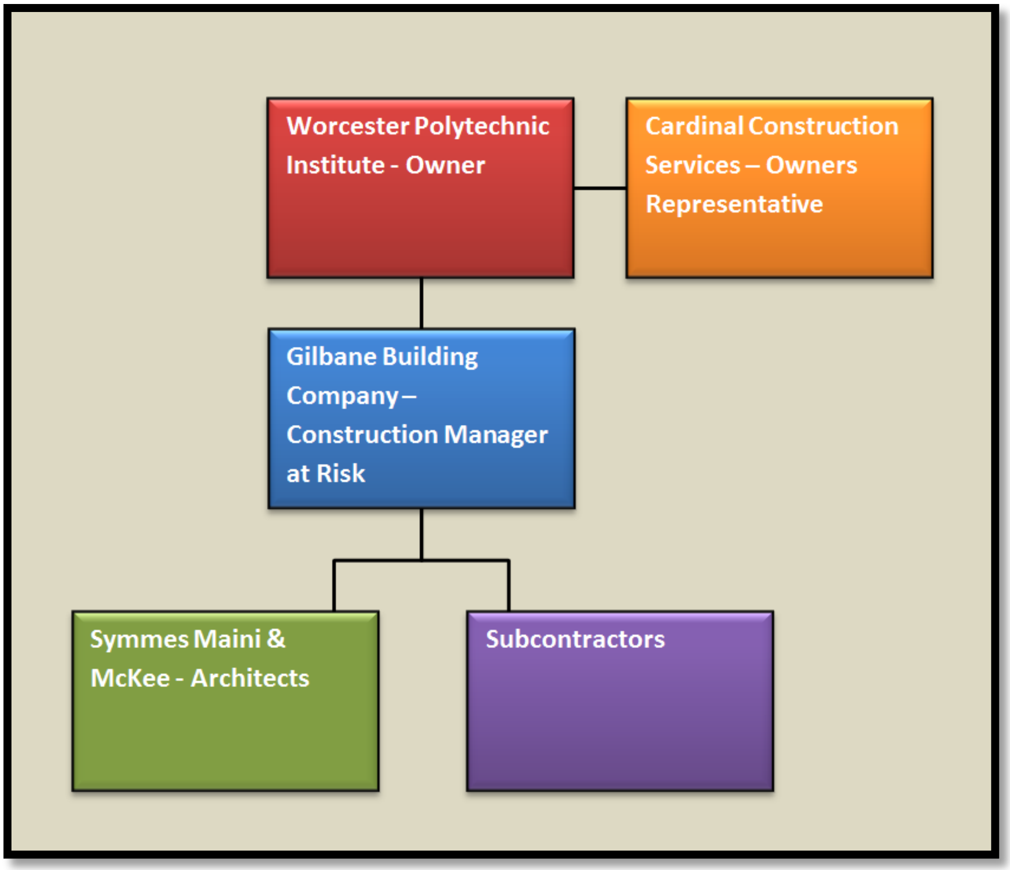

Figure 1: Project Team Breakdown

2.1.1 Gilbane Building Company – Design-Builder

Gilbane Building Company is officially the design-builder for the WPI Parking Garage (Seiferth, 2012). They handle all management aspects of a project including preconstruction, construction management, subcontracting and consulting. They are also responsible for the completion of the structures design. Gilbane is responsible for overseeing all aspects of the project and works in conjunction with WPI, the WPI representative, architects and engineers to oversee and facilitate the completion of this project.

According to Lyndsy Seiferth, the project engineer, WPI incorporated GBC early on in this project, before the formal designs were developed. GBC has a strong working relationship with

WPI based on previous successful construction projects at the university. Once GBC provided an estimate for the project, WPI briefly looked at alternative companies to compare as reference to confirm GBC's bid for this project was a fair price (Seiferth, 2012). This contract, as the design-builder, allows the owner to appoint a responsible construction management company early on the project before formal designs are completed, but is responsible for overseeing the architectural and structural designs are met. GBC bid 100% of all work and then makes a profit off of a certain percent of the construction costs. Once the guaranteed maximum price (GMP) for this project is determined, GBC will be responsible for completing the parking garage within the determined budget. (Seiferth, 2012)

2.1.2 Cardinal Construction – Owners Representative

Cardinal Construction provides owner representative services for the completion of this project. The owner representative handles many aspects of the project that the owner may be less familiar with, such as project "feasibility, project budgeting, and architect selection in the Preconstruction stage, through commissioning, final occupancy, and project close-out" (Cardinal Construction, Inc). Overall, they advocate on behalf of the client, WPI. WPI has worked with Cardinal on past projects and has a positive working relationship with them. (Arthaud, 2012)

2.1.3 Symmes Maini & McKee Associates – Architectural and Structural Design

Symmes Maini & McKee Associates (SMMA) describes themselves as "an integrated design firm offering architecture, engineering, interior design, and planning services." (SMMA, 2012). Since this company is both engineering and architectural, they are responsible for the architectural and structural designs and well as adhering to all building codes, planning and zoning laws. Gilbane hired SMMA for this project to satisfy the structural design while providing an architectural design concept that the client approves of conceptually. This requires

SMMA to question both WPI and Gilbane extensively about their preferences on this project to determine that SMMA has successfully designed a project that pleases all parties. The architect for this project makes the major design decisions and then requests the input of the owner to confirm their vision and control many of the detailed aspects of the project (SMMA, 2012).

2.1.4 Vanasse Hangen Brustlin, Inc. – Land Development

Vanasse Hangen Brustlin, Incorporated is a planning, transportation, environmental and land development design company. They are used as SMMAs design consultants to develop the athletic field to make sure it is a stable and safe environment, since they have designed similar projects in the past that work with elevated athletic fields.

2.1.5 McPhail Associates, Inc.

To determine the best course of foundation design the company McPhail Associates was hired to do preliminary ground testing on the site and provide recommendations. McPhail Associates is a Geotechnical Engineering firm based out of Cambridge Massachusetts. The company does work with private and government contractors for geotechnical investigations and also geo-environmental work. (McPhail, 2012)

2.2 Weekly Progress Meetings

Keeping open lines of communication is an essential aspect of a successful construction project management. In order to help accomplish this, Gilbane holds weekly progress meetings with the major parties involved in the parking garage project. The main focus of these meetings is to keep open lines of communication through all major participants involved in the project. The meetings are facilitated by Gilbane's project manager, Neil Benner, but all parties are encouraged to become involved in discussing any aspects of the project they deem important. One of these meetings is known as the “Owner Meeting”. The main objective of these meetings is to report on construction progress, discuss major milestones and project design and budget updates. Topics typically discussed include construction updates and changes to the construction schedule, construction and design concerns, award of subcontracts, architectural features/submittals, and other issues that may rise with the project. Gilbane shares documentation which includes meeting minutes, budget updates, changes and alternatives to the original designs. In some meetings, they provide the samples of different materials such as tiles to help WPI decide on different architectural aspects.

These meetings are comprised of the main contributors of the project: Gilbane Building Company, Cardinal Construction, Symmes Maini & McKee Associates, JJS Sports and WPI representatives. GBC is represented by Bill Kearney, project executive, Neil Benner, project manager and Lyndsy Seiferth, project engineer. The owner’s representative from Cardinal Construction is Brent Arthaud, who also attends the weekly meetings. The WPI community members that attend these meetings include: Dana Harmon, Athletic Director; Alfredo DiMauro, Assistant Vice President of facilities; Jeffery Solomon, Chief Financial Officer; Sean O’Connor, WPI Network Operations; and Janet Richardson, Vice President of Student Affairs.

2.3 Project Estimating, Budgeting, Bidding and Payments

Before any project begins construction, it is extremely important to decide how the project will be funded, what is appropriate to spend on the project and if the allocated budget is realistic for what the client wants to construct. The decided budget for a project is based on finding a balance between what the client wants and the amount of money the client is willing to spend to achieve the project. This depends on the architects, construction managers, owners, and any other parties involved in the process. (Oberlender, 2000)

The owner and architect complete preliminary designs and discuss what aspects they want to incorporate into the project. Gilbane and other construction manager companies then had the opportunity to bid and negotiate the project for WPI. This bid was the preliminary budget for the project. Since it is a design-build construction project, the final designs were not completed and therefore could not have an exact accurate price which eventually becomes the Guaranteed Maximum Price (GMP) for the project.

The preliminary budgets are not always accurate because different stages in the design are still being determined. Table 1 below shows the preliminary budget of this construction project with the allocations for different scopes of work. As the project comes further along, Gilbane is able to attain more accurate pricing on certain aspects of construction and is able to fine tune the original bid (Seiferth, 2012). When creating the project budget, there are many unforeseen circumstances that often appear. One way to protect the design-builder at risk from unforeseen circumstances is to add a contingency to the budget. Typically the design-builder will add a percentage to the budget to account for any uncertainties, called a contingency. This may include a change in the soil conditions (effecting the foundation requirements) or poor weather conditions that may add costs to the project that were not already accounted for. Overall, the contingency is a safety net that ensures that smaller unexpected changes in the project will not have detrimental effects on production.

Table 1: Preliminary Construction Budget

BP	DESCRIPTION	PRELIMINARY BUDGET	
01A	GENERAL REQUIREMENTS	$	230,125
02A	SITEWORK AND FIELDS	$	4,907,288
02B	PRESSURE INJECTED FOOTINGS	$	260,399
02C	LANDSCAPING	$	135,000
02D	FIELD TURF	$	637,000
03A	CONCRETE	$	1,469,124
03B	PRECAST CONCRETE	$	3,800,000
04A	MASONRY	$	197,680
05A	MISC METALS	$	109,975
	FENCING	$	-
06A	GENERAL TRADES	$	153,046
	SPECAILTIES	$	-
	Overhead Doors	$	-
	MILLWORK	$	-
	PAINTING	$	122,489
07A	ROOFING	$	213,200
07B	WATERPROOF	$	-
08A	CURTAINWALL	$	331,965
10A	SIGNAGE	$	40,000
10B	SPORTS NETTING	$	121,750
14A	ELEVATORS	$	80,000
15A	MECHANICAL	$	1,147,042
16A	ELECTRICAL	$	795,796
16B	SPORTS LIGHTING	$	634,662
	SUBTOTAL	$	15,386,541
	DB CONTINGENCY (5%)	$	769,327
	BUILDING PERMIT	$	112,009
	CDIC - SUB BONDING (1.20%)	$	184,638
	SUBTOTAL	$	1,065,975
	AE FEES	$	850,000
	CM GENERAL CONDITIONS	$	685,284
	CM FEE	$	323,172
	CM GEN LIABILITY INSURANCE	$	156,046
	SUBTOTAL	$	2,014,502
	TOTAL	**$**	**18,467,018**

WPI accepted Gilbane onto the project not only because their price was competitive, but because Gilbane has a positive working relationship with WPI. Using them on both the recreational center and the parking garage would also help keep mobilization and demobilization cost lower.

Since this was a design build project, not all aspects of the design had been completed at the time of the bid.

WPI has unofficially set the project budget at $20 million, but as of December 2012 WPI had not formally signed a GMP with Gilbane (Seiferth, 2012). A GMP is a contracted maximum amount of money that the design-builder agrees to construct a structure for. This includes all materials, labor, equipment, supervision, insurance and all other aspects considered to construct the building. This is different from the preliminary budget because it holds the design-builder responsible for completing the project for the contracted amount under all circumstances, where a preliminary budget is subject to change. The GMP protects the client by making sure the construction manager does not go over the agreed contacted amount. In the event that the changes are made to the project after the GMP is established, owner must approve the changes in order for the design-builder to be paid for the additional work. This is considered a change order, which will be submitted to change the value of the contract. (Oberlender, 2000)

Gilbane started design of this project without a formal GMP as a way to help fast track the project. This allows the construction of the foundation and other preliminary parts of the construction to take place while other, more detailed design aspects of the project, such as the locker rooms and concession stands, may be determined at a later date. Constructing while designing allows the project to be built faster since the complete designs do not need to be finished from the beginning of the project. The only detraction from this is that changes to the project during construction may be costly if not foreseen far enough in advance. (Oberlender, 2000)

2.4 Earned Value Analysis (EVA)

Earned value analysis is a method to compare the planned progress of a construction project to the amount of actual work completed. The budgeted cost of work scheduled (BCWS) represents the allocated funds that are planned to be budgeted for a project. "It is determined by cost loading the CPM diagram to determine the distribution of cost in accordance with the project plan" (Oberlender, 2000). This is also represented by the S-curve, which compares cost at different schedule phases of the project. The actual cost of work performed (ACWP) represents the amount of money that has been spent to date regarding the project. This is based off of the projects finical records. The budgeted cost of work performed (BCWP) shows how much money the job has made based on the work that has been performed. The equations below show how BCWS, ACWP and BCWP can be used to calculate variances, indices and forecasts. (Oberlender, 2000)

Equation 1: Cost Variance

$$Cost\ Variance\ (CV) = BCWP - ACWP$$

Equation 2: Schedule Variance

$$Schedule\ Variance\ (SV) = BCWP - BCWS$$

Equation 3: Cost Performance Index

$$Cost\ Performance\ Index\ (CPI) = \frac{BCWP}{ACWP}$$

Equation 4: Schedule Performance Index

$$Schedule\ Performace\ Index\ (SPI) = \frac{BCWP}{BCWS}$$

Equation 5: Budget at Completion

$$Budget\ at\ Completion\ (BAC) = Origanal\ Esimate$$

Equation 6: Estimate to Complete

$$Estimate\ to\ Complete\ (ETC) = \frac{BAC - BCWP}{CPI}$$

Equation 7: Estimate at Completion

$$Estimate\ at\ Completion\ (EAC) = ACWP + ETC$$

Overall, cost variance compares the work paid for to the work actually performed. Negative CV values show that the actual cost of the work was more than the budgeted amount, causing a cost overrun. Positive CV values show the opposite, which is what construction companies stride for. It is a goal in construction management for the ACWP to be less than BCWP. This allows the construction manager to increase the revenue without increasing the owners' costs. The SV works similarly by comparing the earned and planned schedule. Having fewer BCWP than BCWS shows that the workers are taking less than the scheduled time to complete tasks, which is also a desired trait in construction. Cost and schedule performance indices show if the cost and schedule of the project is on track. CPI and SPI values of 1.0 or greater indicate the project is ahead of schedule and under budget, respectively. (Oberlender, 2000)

2.5 Project Scheduling

Project scheduling is considered the management forecast of when and how long trade contractors and suppliers will be on a building project. This aspect of the project is typically completed by the construction manager, since they are ultimately responsible for the success of the construction. This helps the construction process to be planned well in advance to make sure the project is completed within the given timeline. Scheduling allows the construction manager and owner to get a realistic view of when the project will finish. Keeping an open line of communication regarding the schedule between the construction manager, subcontractors, architects and owner is essential for a successful project. There is a variety of different ways to display a construction schedule when comparing, time, cost and critical activities. (Owners Builder)

2.5.1 Lazy-s Curve

The lazy-s curve graph plots the project work against the schedule. This graph is referred to as an "s" curve because it typically loosely resembles an "s" shape. Normally in a project, construction work will start out slower and then will suddenly increase the volume of work. After the majority of work is completed, the work load will fall light again. As you can see in Figure 2, this project follows the typical s curve. (Mubarak, 2010)

Discipline	W/F (%)	Plan (%)	Actual (%)	Dev (%)
Temporary	6.26%	100.00%	100.00%	0.00%
Civil	21.44%	98.79%	98.88%	0.09%
Steel Structure	3.45%	94.78%	97.10%	2.32%
Fire Proofing	3.29%	81.74%	83.62%	1.89%
Arch/HVAC	4.94%	95.32%	96.29%	0.97%
Equipment	9.42%	86.06%	86.77%	0.71%
Tanks	7.77%	98.67%	99.21%	0.53%
Piping	26.21%	83.48%	81.56%	-1.92%
Electrical	6.35%	77.68%	82.80%	5.11%
Instrument	5.28%	49.00%	51.60%	2.60%
Insulation	1.16%	25.68%	27.17%	1.48%
Painting	1.43%	58.35%	59.51%	1.16%
Commissioning	3.00%			
Total	100.00%	84.41%	84.73%	0.31%

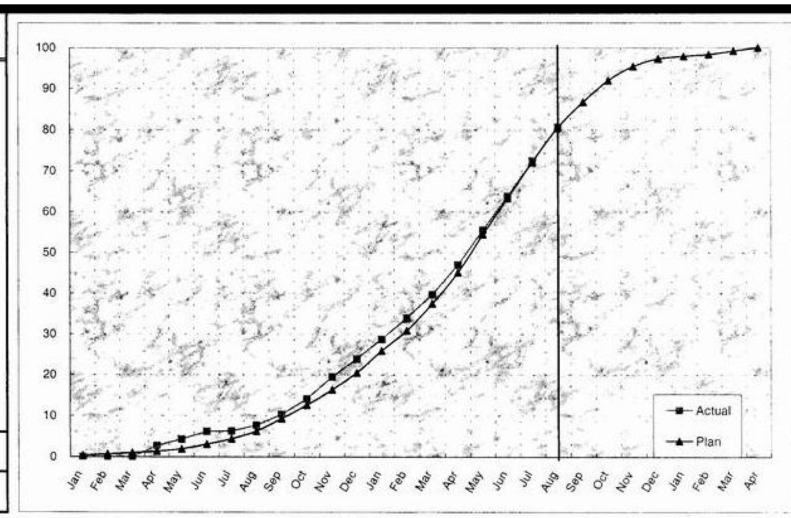

Figure 2: Example of Lazy S Curve relating cost and time.

2.5.2 Gantt Chart

A Gantt chart is a visual bar chart that displays the schedules start and finish dates of activities within a project. These charts may also show dependency between activities. Gantt charts are a good visual way to display which activities coincide during a given time in the construction project. Figure 3 shows an example of a Gantt chart.

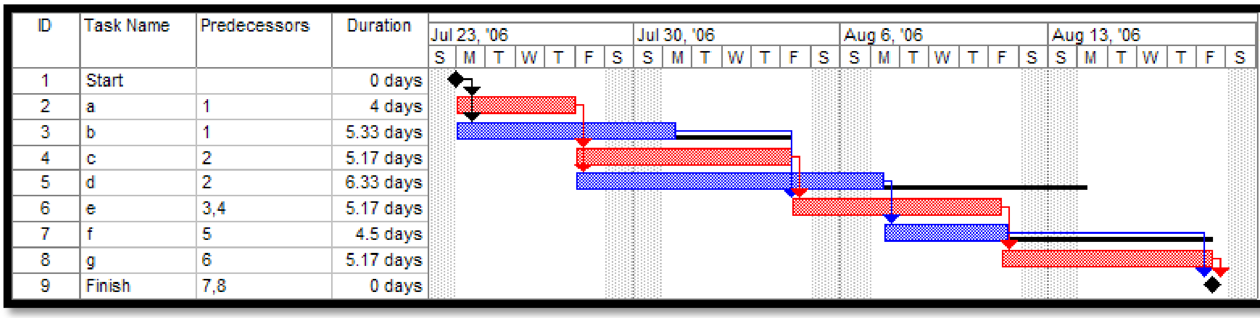

Figure 3: Example Gantt Chart

2.5.3 Critical Path

The critical path method (CPM) allows the project schedule to be established based on the most important tasks to complete the project on time. The CPM identifies the start date, duration, and end date of each activity that is required for the project. If the start date of a critical path task is delayed, it extends the entire schedule of the project, unless the lost time is made up later in the schedule. Figure 4 shows a typical critical path method diagram. The CPM allows the construction manager to constantly understand the importance of each activity and compare it to other activities that may allow some float time. Appendix A shows terms associated with the CPM and their definitions. This has seen to be an effective method of scheduling and is well respected in the AEC Industry. (Oberlender, 2000)

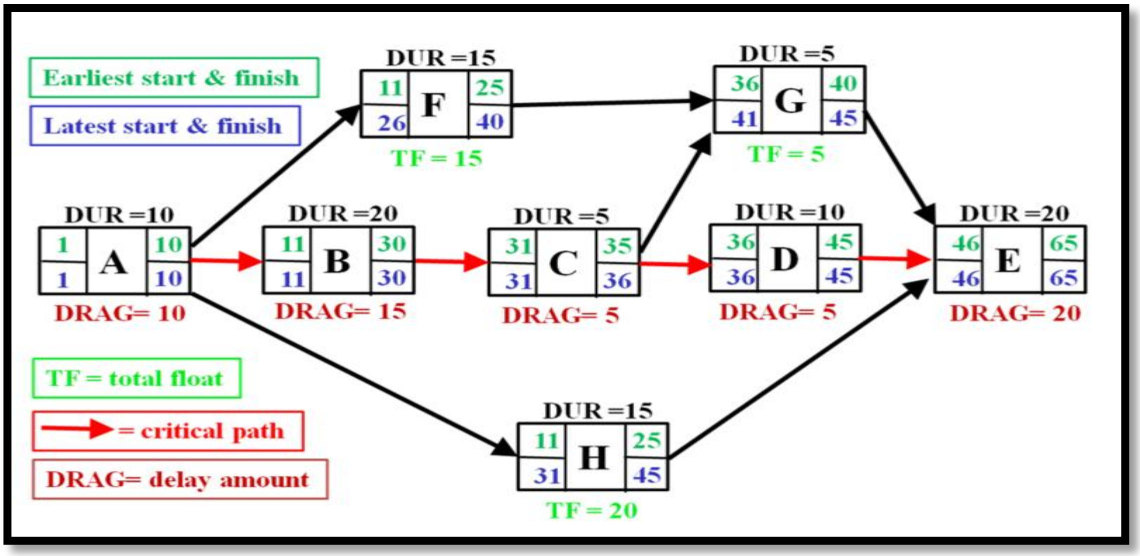

Figure 4: Critical Path Diagram

2.5.4 Gilbane's Card Trick Schedule Meeting

In the beginning of the project, a meeting was held with the construction management team and the major subcontractors. This meeting is referred to as a card trick schedule meeting. The purpose of this meeting is to complete a detailed schedule of the major milestones to determine how the project will be constructed on time. This meeting is managed by the GBC project schedule. The project schedule has an overall idea of the schedule coming into the meeting. Keeping open lines of communication with all the subcontractors is important to the success of the project. It allows the subcontractors to understand the other trades being completed around their schedule and allows the subcontractor and project schedule to directly communicate and agree on a schedule. (Murphy, 2012)

A paper copy of the schedule was posed on the wall as a working visual aid to help develop the schedule. Each week was represented as 3 inch sections as seen in Figure 3 where each major field of work is written on a 3 inch post-it note and is places in the appropriate week. Once all major trades and milestones have been added to the schedule, the scheduler creates an electronic copy of the schedule using primavera scheduling software. This schedule is sent out to the major subcontractors and they must confirm that they agree to complete their scope of work within the designated timeline they agreed on. This method keeps all parties involved on the same page. (Murphy, 2012)

Figure 5: Gilbane Card Trick Board

2.6 Building Information Modeling

Typically in construction, 2D drawings are created by the architect to show the structural and architectural components of the structure. These 2D drawings are a major asset for the contractor to build the structural components of the construction project. However, since these 2d drawings focus more on the structural components such as structural beams, walls, and door placements, it leaves little room to show areas of great detail. This can become challenging for the owner to visualize what the finished construction project will actually look like.

For this reasoning, 3D Building Information Modeling has become an important tool in the architectural, engineering, and construction (AEC) Industry. It allows the construction project to be shown in height, width and depth with all the intricate details of the project. These models have also been designed to include real time development, special relations and material quantities used for the project, to help get a better idea of what to expect. This allows the owner to get a detailed sense of what the actual project will look like. Therefore, costly changes are more likely to occur before the construction actually takes place, since the client has a change to see what they will be receiving. Overall the use of BIM improves the planning, design and construction of any project. (Reinhardt, 2010)

2.6.1 History

Building Information Modeling has been in the industry since the early 1980's (Carmona, and Irwin, 2012). However it has not become popular within the AEC Industry until recent years. The AEC Industry has notices how critical BIM can be and leading companies have begun to look for employees who have BIM related knowledge and skills.

There are a variety of 3D BIM programs that are considered the first BIM for the AEC Industry, however it is overall accepted that it emerged in the 1980's. Since then, many different companies and types of 3D computer aid design software have developed to help the production of the AEC Industry. Even though BIM has been around for over 30 years, it has only become popular recently. Through this development and constant improvement, Autodesk created the

BIM program called Revit, which is a highly used and respected program by engineers and architects. (Weisberg, 2008)

Revit allows users to interpret the 3D model with 2D drafting elements and access building information from the models database. It is capable of going beyond 3D but tracking the progress and amount of materials through different stages of the project. Revit is considered a favorable BIM program because of its easy-to-use platform designed specifically for the AEC Industry to complete bid to closeout planning of construction projects. Revit's user friendly interface allows easy revisions to any project and allows the user to synchronize the program with real-time construction phases. (Weisberg, 2008)

2.6.2 Modeling

One of the key words in building information model is information. BIM is much more advanced than traditional 2D or even 3D computer drawings. One great aspect of the program is the ability to develop spatial relationships.

Unlike traditional 2D drawings such as AutoCAD, different building elements understand their relationships and help define each other. For example, a door or window cannot exceed the size of the wall it is a part of. If it is later removed, the door and window are removed as well, since realistically, a door or window cannot exist without the wall it is placed in. features such as this allow renovations to the design to be easy to complete and leave less room for human error. If certain relationships are desired for a project, they can be created, such as making light switches within a certain distance of every door. (Building Information Modeling, 2010)

Typical 2D drafting requires manual takeoffs of construction material quantities. Since BIM works in 3D, material quantities can be calculated automatically. BIM can look at a reinforced concrete floor and determine the quantities of concrete and steel required. This is also important when ordering smaller, more diverse items such and door hardware which may vary depending on the type of door. Changes to the project are easy to update and a new takeoff can automatically be created. Some software connects models with their specifications, allowing an element such as a window in the BIM to be linked to a note describing the section in the specifications regarding the type of window required. (Building Information Modeling, 2010)

BIM can also help visualize the schedule. Gantt charts have been a critical part of construction planning for decades, but they lack a visualization of what the project phases actually look like in real time. BIM is the missing aspect that allows architects and construction managers the chance to show the project as a 4D analysis. By combining the 3D building information model with a project schedule, the project can be seen within a timetable. This allows four dimension animations that envisage each step of the project phase at the needed time that provides an intuitive interface for the project team as well as the owner and other invested members. (Building Information Modeling, 2010)

BIM allows multiple users to work on the same file to avoid clashes between disciplines. BIM creates a mast file and then allows different users to work independently within the file. Mechanical and electrical work can be designed by different individuals in the same drawing and will not allow multiple sections in the same position. For example, BIM will not allow electrical wires and plumbing to be designed in the same space (Autodesk, 2012). The Heathrow Airport Terminal Five in London is a great example of a large scale project that was completed solely off one BIM file. (Garrett, 2008)

3.0 Incorporating Building Information Modeling and Construction Management

Building Information Modeling (BIM) can be a great asset to the construction industry. It has been used to visually display a 3 dimensional projection of the project contrasting the planned and actual construction progress. This chapter focuses on the development of the BIM model for the parking garage structure.

3.1 3D BIM Development

Building information modeling has become very important to the construction management industry. The basis of our BIM model was created with Revit Structural. This software program allowed us to accurately develop the structure of the parking garage. The model was based off of the structural and architectural two-dimensional drawings provided by SMMA and Gilbane Building Company.

The development started in Revit Structural by setting up the different levels and grid lines. The grid lines, which mimicked the structural drawings gridlines, were used to help provide a reference for the different aspects of the structure. Figure 6 below shows the plan view of the garage level of the model with grid lines. Levels depict each different floor in the structure. The levels included the subfloor or soil level, level one which is the garage level, and the second level which shows the athletic fields. These boundaries set up the basis for creating the structural components of the building.

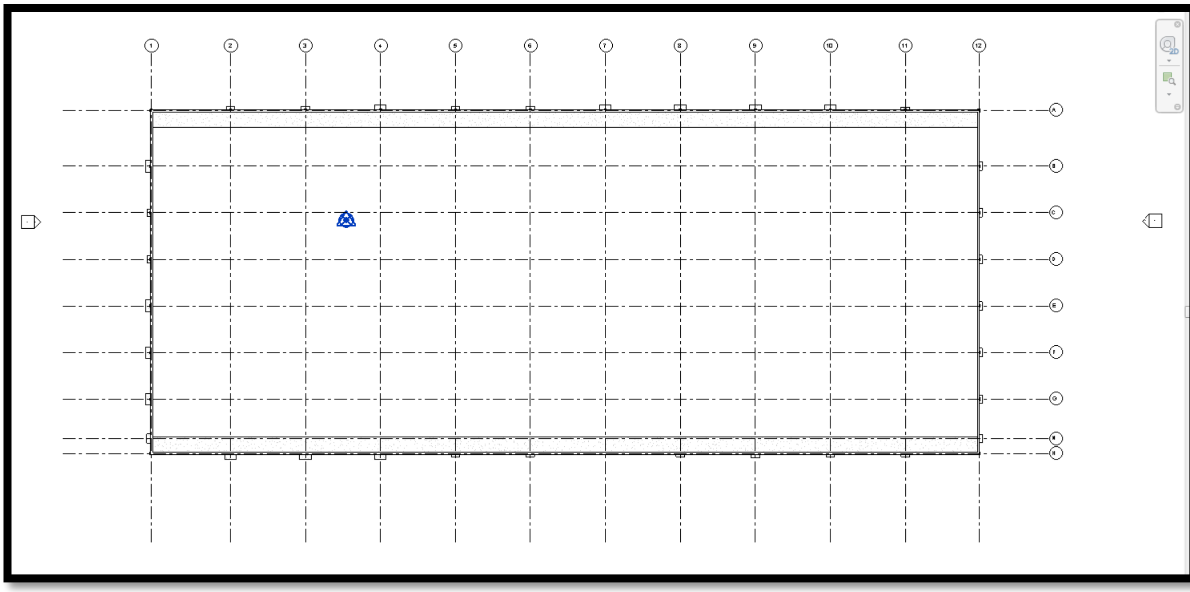

Figure 6: BIM Foundation with Grid Lines

Since there are varying soil conditions throughout the base of the garage, both deep and shallow foundations had to be used. The foundation piles were inserted at each gridline intersection, similar to the architectural drawings. In areas where there was bedrock closer to the surface, footings with a smaller surface area were used and did not need to be very deep. On areas where the soil had a lower bearing capacity, Pressure Injected Footings (PIFFs) reaching deeper depths were installed to support concrete pile caps that were put into place. The foundation was then finished by adding a foundation wall on the perimeter to help support the interior structural shearing walls. Once the foundation was completed, compacted backfill and a two-binder asphalt layer were laid down on top of the footings. Figure 7 shows a 3D rendering image of a deep foundation piles under the foundation floor from the BIM model.

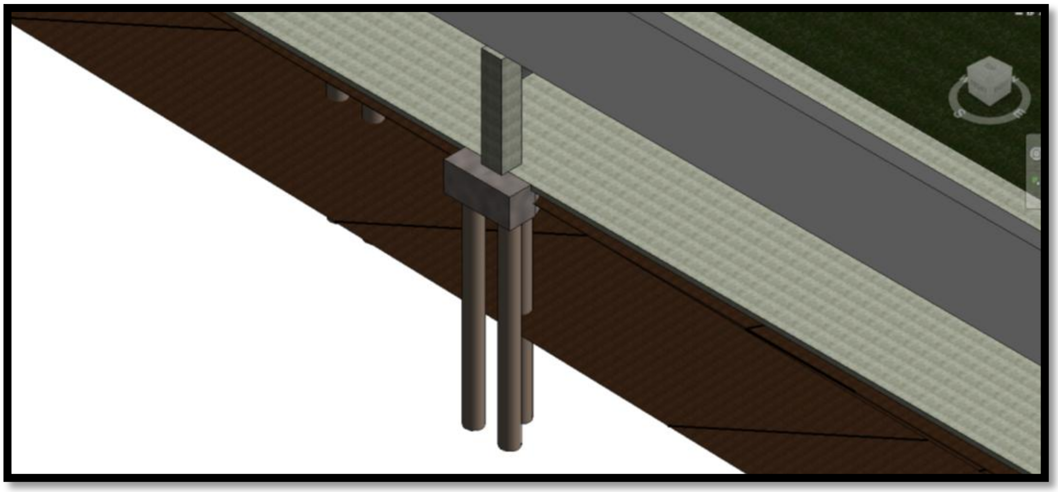

Figure 7: Deep Foundation Pile

After the foundation was solidly built, the main components of the garage were added. This started by putting columns on the garage level. These reinforced concrete columns were spaced out on the garage level. For maximum ventilation, much of the garage level was left open and walls were erected in only two of the four edges of the parking garage. On the other sides of the structure, columns were placed up against the edge of the garage to support the upper level. We were then able to insert precast concrete I beams and double tee beams as well as the girders to support the roof structure of the garage. Figure 8 shows the side view of the garage, exposing the beams and double tee beams.

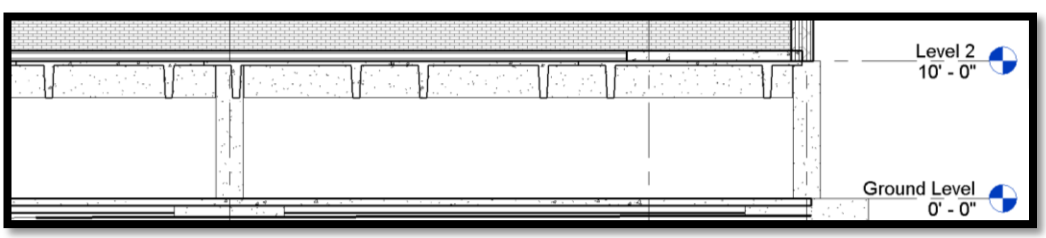

Figure 8: Side View of Beams and Double Tees

The last area of the structure was the athletic roof. We started with a concrete slab as a base. Once this was added, we created the layers of the turf. This was an extremely challenging aspect since the athletic turf had many layers to provide proper drainage of the field surface. We modeled these layers by adding a floor with multiple layers. These layers included a sub base, filter fabric, gravel, sand and a top layer of grass as seen in Figure 9. Outside of the turf, there were two sidewalks that run the length of the field.

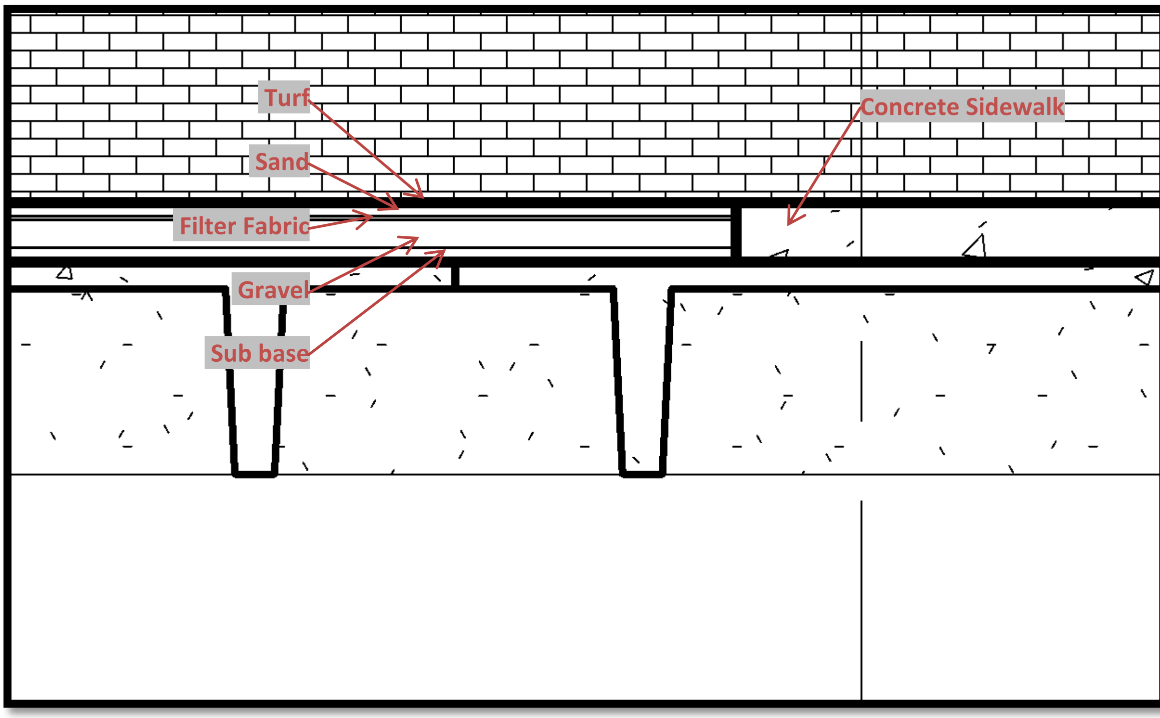

Figure 9: Synthetic Turf Layering

Along with the structure the predicted soil profile was added to the model. This profile was created by drawing top surfaces to represent the different layers of soil. This allowed for the soil profile to be viewed along with the completed structure and look at the resulting foundation with respect to the soil layers.

3.2 4D Time Analysis

A 3D model can be phased to display the gradual progress of construction. A 4D mode list generated when each phase is combined with the actual dates of execution of each phase. This 4D model is created by integrating Microsoft Project schedule with the Building Information

Model. We started with the original Gilbane schedule for this project and entered the data into Microsoft Project. Each main bid package of work was broken down into its anticipated schedule as shown in Table 2 below. This schedule corresponds to the bid packages organized by Gilbanes card-trick meeting in September. Since the purpose of this schedule was to reflect future trades, it only shows dates going back to August 2012, even though construction started earlier than that.

Table 2: Major Scopes of Work from the Gilbane Preliminary Parking Garage Schedule

Task Name	Duration	Start	Finish
EXCAVATION, SHEETING & SITEWORK	98 days	Mon 8/6/12	Wed 12/19/12
LANDSCAPING	159 days	Tue 8/21/12	Fri 3/29/13
SYNTHETIC TURF	131 days	Mon 7/16/12	Mon 1/14/13
CONCRETE FOUNDATION & FLAT WORK	69 days	Fri 9/14/12	Wed 12/19/12
MASONRY & CMU	77 days	Thu 8/9/12	Fri 11/23/12
MISC METALS	105 days	Tue 8/21/12	Mon 1/14/13
WATER & DAMPROOFING	95 days	Wed 7/11/12	Tue 11/20/12
ROOFING	146 days	Wed 7/11/12	Wed 1/30/13
EXTERIOR WINDOW & GLAZING	133 days	Fri 7/20/12	Tue 1/22/13
GENERAL TRADES	133 days	Tue 6/19/12	Thu 12/20/12
ELEVATORS	100 days	Wed 8/1/12	Tue 12/18/12
PLUMBING	151 days	Wed 7/18/12	Wed 2/13/13
ELECTRICAL	124 days	Fri 7/13/12	Wed 1/2/13
SPORTS LIGHTING	89 days	Mon 8/6/12	Thu 12/6/12
PROJECT MILESTONES	20 days	Thu 1/17/13	Wed 2/13/13

Within each major scope, the detailed project schedule was completed. This helped separate different divisions of work and show the links within each section. Table 3 shows part of the detailed plumbing schedule. A detailed schedule breakdown can be seen in Appendix B.

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Table 3: Section of the Gilbane Preliminary Plumbing Schedule for the Parking Garage

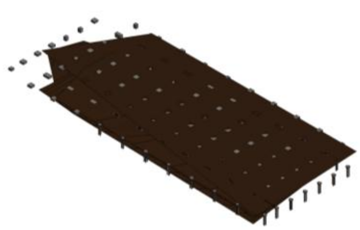
Task Name	Duration	Start	Finish
A/E REVIEW PLMG	10 days	Wed 7/18/12	Tue 7/31/12
A/E REVIEW EF	10 days	Tue 7/24/12	Mon 8/6/12
A/E REVIEW DUCT	10 days	Tue 7/24/12	Mon 8/6/12
A/E REVIEW LOUVERS	34 days	Tue 7/24/12	Fri 9/7/12
INSTALL UG PLUMBING	15 days	Tue 8/7/12	Mon 8/27/12
INSTALL UG STORM LINE G.5 LINE	15 days	Wed 8/8/12	Tue 8/28/12
FAB & DEL EF	30 days	Wed 9/5/12	Tue 10/16/12
INSTALL UG PLUMBING - A LINE	0 days	Thu 9/6/12	Thu 9/6/12
A/E APPROPVE TRENCH DRAIN	2 days	Thu 9/6/12	Fri 9/7/12
PREP & PLACE SOG @ 1 LINE	2 days	Mon 9/10/12	Tue 9/11/12
MANUF SUB SD FOR TRENCH DRAIN	5 days	Mon 9/10/12	Fri 9/14/12
FAB & DEL DUCT	10 days	Tue 9/11/12	Mon 9/24/12
FAB & DEL LOUVERS	10 days	Tue 9/11/12	Mon 9/24/12
R.I.O.H.. PLMG / SPKL, GROUND LEVEL 1- 8	64 days	Thu 9/13/12	Tue 12/11/12
FAB & DEL TRENCH DRAIN	30 days	Mon 9/17/12	Fri 10/26/12
INSTALL PLUMBING DRAINS - SEQ 1	2 days	Wed 9/26/12	Thu 9/27/12
INSTALL PLUMBING DRAINS - SEQ 2	2 days	Fri 10/5/12	Mon 10/8/12
R.I. PLUMBING BETWEEN CMU WALLS@ GARAGE LEVEL	10 days	Fri 10/5/12	Thu 10/18/12

The original schedule was extremely detailed compared to our 3D BIM so we created a simplified schedule to depict the major scopes of work, which can be seen in Table 4. Looking at these two simplified schedules, we were able to integrate them with the 3D model. This allowed us to compare the different stages of construction at monthly increments as well as compare the predicted schedule to actual construction.

Table 4: 4D Phasing Schedule

Task Name	Finish
Complete Prelim Excavation	
Install Foundation Footings	Fri 8/31/12
Pave Foundation Floor at Garagr Level	Fri 9/7/12
Erect Exterior Precast Concrete	Thu 9/27/12
Install Roofing	Mon 12/24/12
Install Turf Field	Fri 5/3/13

By imputing the modified Microsoft Project Schedule from Table 4, we can view each major construction milestone in phases as it was being built. Figures 10-14 below represent different phases of the 4D model.

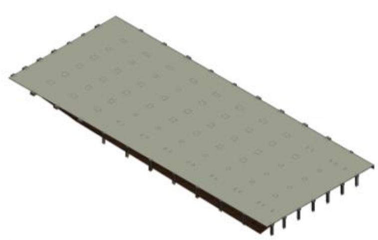


Install Foundation Footings (PIFs)

Scheduled (9/7/12): NA

Actual: August 31, 2012

Figure 10: Completed Foundation Footings



Pave Foundation Floor at Garage Level

Scheduled (9/7/12): September 7, 2012

Actual: September 7, 2012

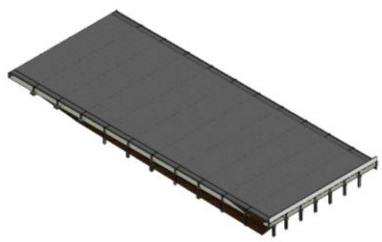
Figure 11: Completed Foundation and Garage Floor

Erect Exterior Precast Concrete (Second Level)

Scheduled (9/7/12): September 27, 2012

Actual: October 2, 2012

Figure 12: Erect Precast Concrete



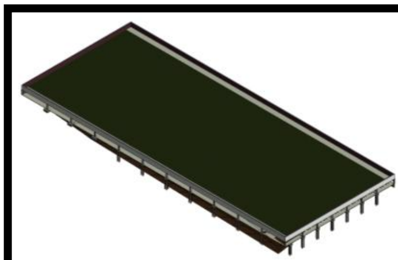
Completed Roofing (standing seem roof)

Scheduled (9/7/12): December 24, 2012

Scheduled (12/18/12): January 30, 2013

Actual: TBD

Figure 13: Structural Roof with Double Tee Beams



Completed Installation of Turf Field

Scheduled (9/7/12): January 13, 2013

Scheduled (12/18/12): January 29, 2013

Actual: To be finished by mid-May

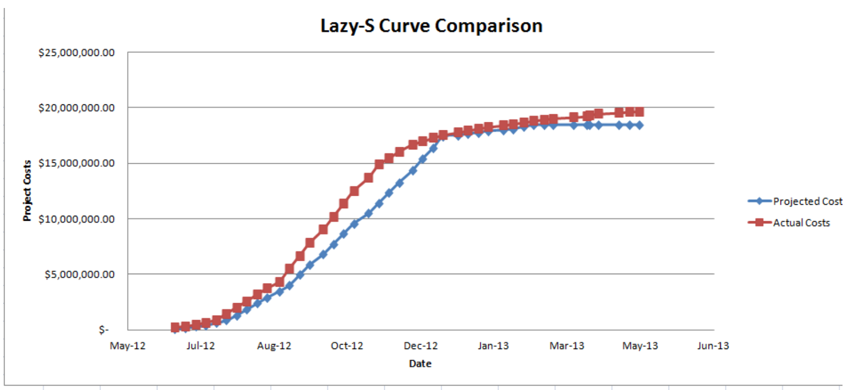
Figure 14: Completed Turf

In early September 2012, Gilbane was within two days of the actual schedule paving the paving garage floor on September 12th compared to the 10th. According the Lyndsy Seiferth, the schedule is considered to stay relatively on track.

Later on in the project certain circumstances came into play. Although the schedule expected the project to be completed in early February, it did not account for cold weather. The main problem with cold weather was that the synthetic turf could not be sewn on the field if the temperature was less than 45 degrees Fahrenheit. This was a major challenge since it is a five week process that was originally scheduled to take place in early December, where temperature averages are typically between 23 and 36 degrees Fahrenheit (Monthly Averages for Worcester, MA). Although Gilbane Building Company was optimistic in hoping for a warm winter, they determined the more practical option was to have to parking garage completed by the early January, as requested; but the athletic turf could resume construction in later in the year when there is warm enough weather. As of January 2013, the turf installation has been delayed until early March.

3.3 5D Cost Analysis

Project costs are another important aspect of this project to consider. From the beginning of this project, the WPI trustees and GBC agreed not to exceed the budget of $20 million. As of now, the project is within this budget but not without overcoming certain hurtles. Some of the budgets for different scopes of work have been right on track. For example, the site work budget which was estimated at $4,907,228 is currently as $4,728,000. This shows that the site work and excavation that was needed is on track. However, other aspects of work such as the miscellaneous metals have hit challenges. The original budget was estimated at $100,000. More recently, the current budget to date has already exceeded $380,000. There were a lot of aspects of the construction that were not included with the original miscellaneous metals bid that have been added to the actual. For example, the metal posts that surround the field were not originally considered in the base bid which needed to be added to the scope. Other upgrades were added with the consent of the owners; this includes the type of fencing around the field which was originally anticipated to be steel but was upgrades to be painted black. These added costs slowly increase the overall cost of the scope. Gilbane has been working to the best of their abilities to explore all options for this bid package to make sure that the overall GPM stays below $20 million. They are confident that by moving aspects of the budget around, they will be able to achieve this goal. Figure 15 below, shows a graphical comparison of the projects projected (June 2012) and actual costs (as of September 2012) over the length of the project. Notice that the project costs start slowly, then spike up quickly before the level off again. This shows that the preliminary project costs are small, but once the project has begun, a large portion of the budget must be spent as startup and continuation of the project. Once the bulk of the budget has been spent, the project cost slows as the project finishes.



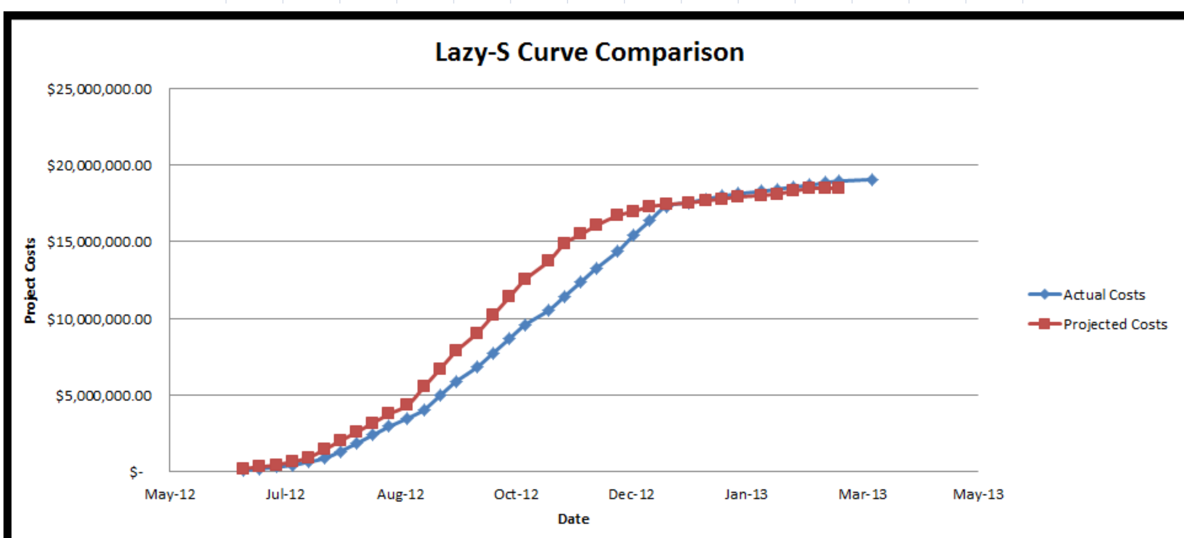


Figure 15: Lazy-S Curve Comparison

Table 5 below shows the changes in the big pricing at different stages in the construction. Some straightforward scopes of work came in right on budget such as the signage. However other aspects, such as the miscellaneous metals, were drastically under estimated. This scope of work changed so drastically because it was originally estimated without the structural metals posts that would hold up the fencing. Adding this feature along with other overlooked parts increased the budget by over $270,000. Although this may seem sever, Gilbane was able to make up major challenges in the budget in other areas, so the overall budget only increased 4%. Part of the increase is also due to the changes that the client requested. WPI chose certain upgrades such as painting the steel fence black and using a different landscape layout than originally designed. According to Brent Arthaud, WPI has been very reasonable with regards to cost and schedule of the project and understand changes happen and require additional costs (Arthaud, 2012)

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Table 5: Budget Changes throughout the Project as of 10/5/2012

BP	DESCRIPTION	ORIGENAL BUDGET	BUDGET UPDATE 5/18/12	BUDGET UPDATE 9/6/12	% Changed
01A	GENERAL REQUIREMENTS	$ 230,125	$ 230,125	$ 230,125	0%
02A	SITEWORK AND FIELDS	$ 4,907,288	$ 4,728,000	$ 4,728,000	-4%
02B	PRESSURE INJECTED FOOTINGS	$ 260,399	$ 361,000	$ 361,000	39%
02C	LANDSCAPING	$ 135,000	$ 135,000	$ 145,000	7%
02D	FIELD TURF	$ 637,000	$ 637,000	$ 563,000	-12%
03A	CONCRETE	$ 1,469,124	$ 1,519,400	$ 1,519,000	3%
03B	PRECAST CONCRETE	$ 3,800,000	$ 3,750,000	$ 3,723,000	-2%
04A	MASONRY	$ 197,680	$ 197,680	$ 306,480	55%
05A	MISC METALS	$ 109,975	$ 109,975	$ 380,000	246%
	FENCING	$ -	$ -	$ 600,000	
06A	GENERAL TRADES	$ 153,046	$ 153,046	$ 220,000	44%
	SPECAILTIES	$ -	$ -	$ 16,627	
	Overhead Doors	$ -	$ -	$ 35,000	
	MILLWORK	$ -	$ -	$ 15,000	
	PAINTING	$ 122,489	$ 122,489	$ 21,000	-83%
07A	ROOFING	$ 213,200	$ 213,200	$ 205,000	-4%
07B	WATERPROOF	$ -	$ -	$ 27,000	
08A	CURTAINWALL	$ 331,965	$ 230,000	$ 229,000	-31%
10A	SIGNAGE	$ 40,000	$ 40,000	$ 40,000	0%
10B	SPORTS NETTING	$ 121,750	$ 121,750	$ 25,000	-79%
14A	ELEVATORS	$ 80,000	$ 62,000	$ 62,000	-23%
15A	MECHANICAL	$ 1,147,042	$ 1,147,042	$ 1,258,900	10%
16A	ELECTRICAL	$ 795,796	$ 795,796	$ 800,000	1%
16B	SPORTS LIGHTING	$ 634,662	$ 634,662	$ 634,662	0%
	SUBTOTAL	$ 15,386,541	$ 15,188,165	$ 16,144,794	5%
	DB CONTINGENCY (5%)	$ 769,327	$ 759,408	$ 565,068	-27%
	BUILDING PERMIT	$ 112,009	$ 126,456	$ 126,456	13%
	CDIC - SUB BONDING (1.20%)	$ 184,638	$ 182,258	$ 193,738	5%
	SUBTOTAL	$ 1,065,975	$ 1,068,122	$ 885,261	-17%
	AE FEES	$ 850,000	$ 850,000	$ 875,000	3%
	CM GENERAL CONDITIONS	$ 685,284	$ 751,325	$ 864,000	26%
	CM FEE	$ 323,172	$ 323,172	$ 323,172	0%
	CM GEN LIABILITY INSURANCE	$ 156,046	$ 153,628	$ 161,329	3%
	SUBTOTAL	$ 2,014,502	$ 2,078,125	$ 2,223,501	10%
	TOTAL	**$ 18,467,018**	**$ 18,334,412**	**$ 19,253,556**	4%

3.4 Communicating with BIM in Weekly Meetings

BIM is very effective in keeping open communications between the owner, architect and construction manager. There were many instances where clear communications between the active parties caused confusions because verbal descriptions of different architectural treatments were often misinterpreted. One specific example of this was during the discussion of the different options of the stone pattern for the south wall. Gilbane was able to bring in samples of 4 different types of stone and explained that a stripped pattern would be displayed with the stone on the south wall. There was a lot of discussion about the different colors and options of the pattern which would ideally be made up of three inch, six inch and 8 inch stone pattern. Although the pattern was described and explained, WPI found it hard to visualize what the different colored stone patterns would look like on a larger scale. Different parties tried to explain their interpretation of how each pattern would look, but it was very inconclusive. This discussion lasted about 45 minutes and by the end of the meeting, the stone patterns were still undecided. This caused the masonry order to be delayed from the original due date. If 3D BIM was created with each alternative architectural design, all parties would have a clear understanding of how each option would look and a decision would have been made quickly and accurately, allowing more time in the meeting for addressing other significant issues. This change in the 3D model can be completed with minimal effort on the computer program. BIM can calculate the number of the different types of stones and give an accurate count of the different prices associated with the different stone options. This is an example of how BIM could be used to help create accurate communications of the different architectural options while still using time effectively.

A second example emphasizes why 3D modeling has become an essential tool are the resources that allow it to go beyond 2D AutoCAD drafting. Originally, Gilbane bid the fence around the fields as galvanized steel. In September, 2012, WPI wanted to see the price difference to paint the fence black to match the fence surrounding the football field. Gilbane provided 4 different alternatives regarding the metals with price breakouts for painting the fence as well as different locations and heights of the fence. The 2D black and white drawings were hard to interpret in understands how the different options would look. After a long debate after the different options, WPI requested to see 3D BIMs of the painted and galvanized steel. Figure 16 below shows a 3D model of the galvanized steel version of the athletic field. This decision, which is on a tight schedule, was prolonged due to the lack of models of the different options. The following week, Gilbane presented the requested updated BIM drawings which helped WPI made an accurate decision on the matter.

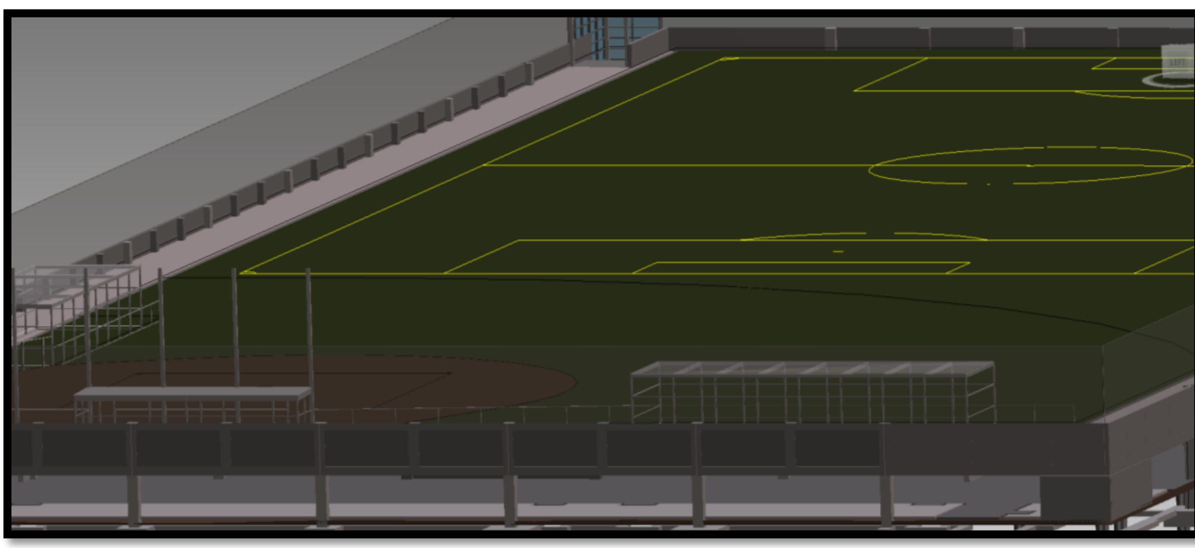

Figure 16: Galvanized Steel Fence BIM (Alavrez & Gomez, 2013)

4.0 Geotechnical Considerations

The foundation of a building is essential to the building process. Since a foundation is the support of the weight of the building, using the correct type of foundation for the project is important. There are two main categories of foundations, shallow and deep foundations. The distinction of these two groups is how far into the soil the foundation is placed. The differences can be seen in Figure 17.

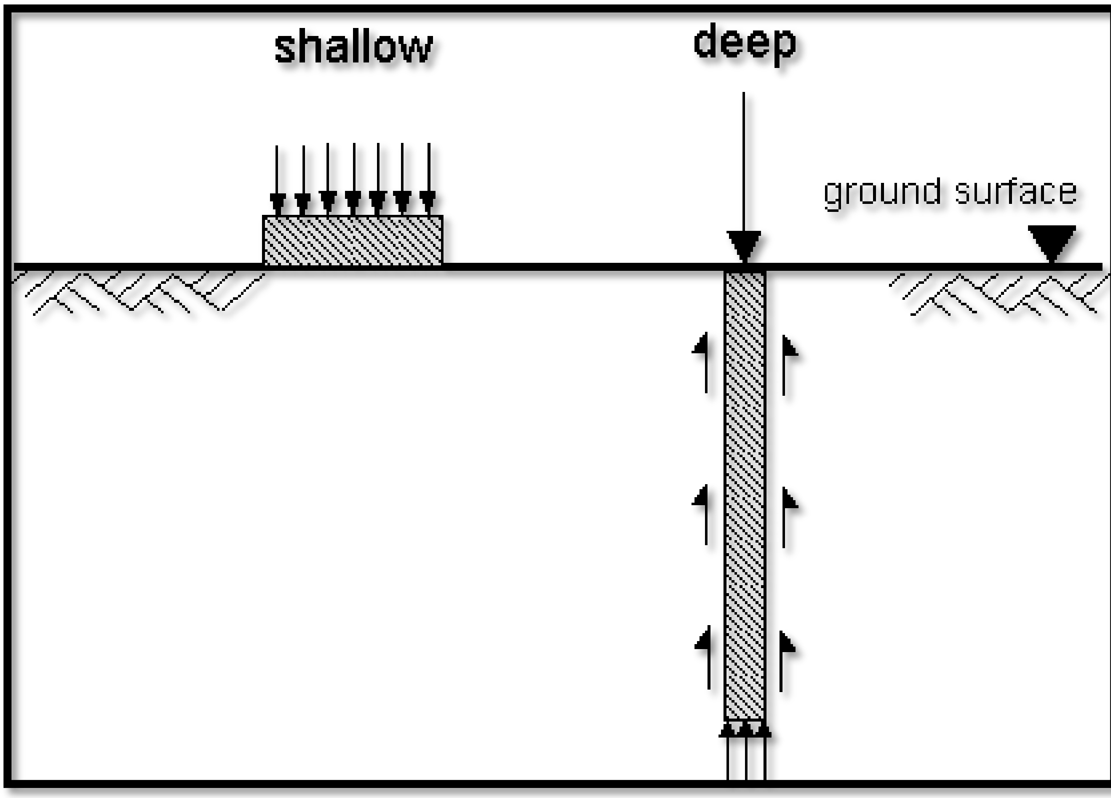

Figure 17: Schematics of shallow and deep foundations (Globalspec 2012)

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4.1 Ground Conditions

The ground conditions of a project describe the layers of soil beneath the construction site. Each site has a unique set of properties due to the distribution of the types of soil at the location. Site tests are done, such as digging test pits and bore holes, to determine the soil layers for the site.

4.1.1 Soil Testing

The proposed site for construction of the parking garage/athletic field was originally playing fields. From surveying done on site it was determined that the original site was relatively level with some sloping off to the outside perimeter of the playing fields. Testing was done on the site in the form of: test pits, bore holes, sieve analysis, in-situ tests, and groundwater observation well. These tests were done to better understand the underlying soil and thus design the foundation appropriately.

The test pits were dug using a backhoe to a depth ranging of 3 feet to 13 feet below the starting ground surface. These pits also provided soil to be brought into the laboratory to be used in sieve analysis. None of the test pits dug encountered any groundwater. The results of the test pit digs were varied throughout the site with some pits encountering organic peat material and varying amounts of urban and granular fill. The test pits were similar in the top layer of topsoil due to the site's original usage. (Geotechnical Report) A test pit log example is shown in Figure 18 which details the information found from a test pit location.

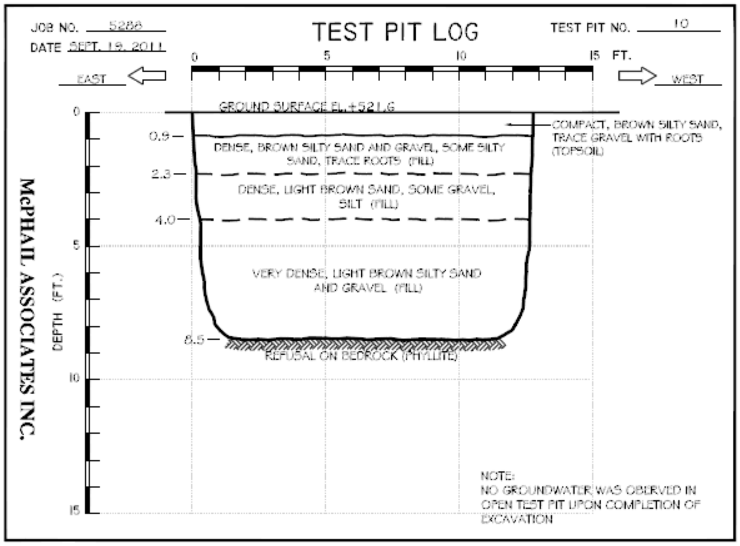

Figure 18: Example of a Test Pit Log (McPhail 2012)

Bore holes were also drilled on site for ground conditions. Boring was done to depths of 8 feet to 22 feet below the surface. These tests were performed at 5 feet depth intervals and boring logs were recorded for each hole, these logs can be found in the Geotechnical Report provided by McPhail Associates. These bore hole reports also give data pertaining to the Standard Penetration Tests (SPT), these in-situ test results are used to determine the pertinent soil properties. Groundwater was encountered in 2 of the boreholes at a depth of 16-17 feet below the surface. A bore hole log is given as an example in Figure 19 which provides details for soil depths from a particular bore hole location.

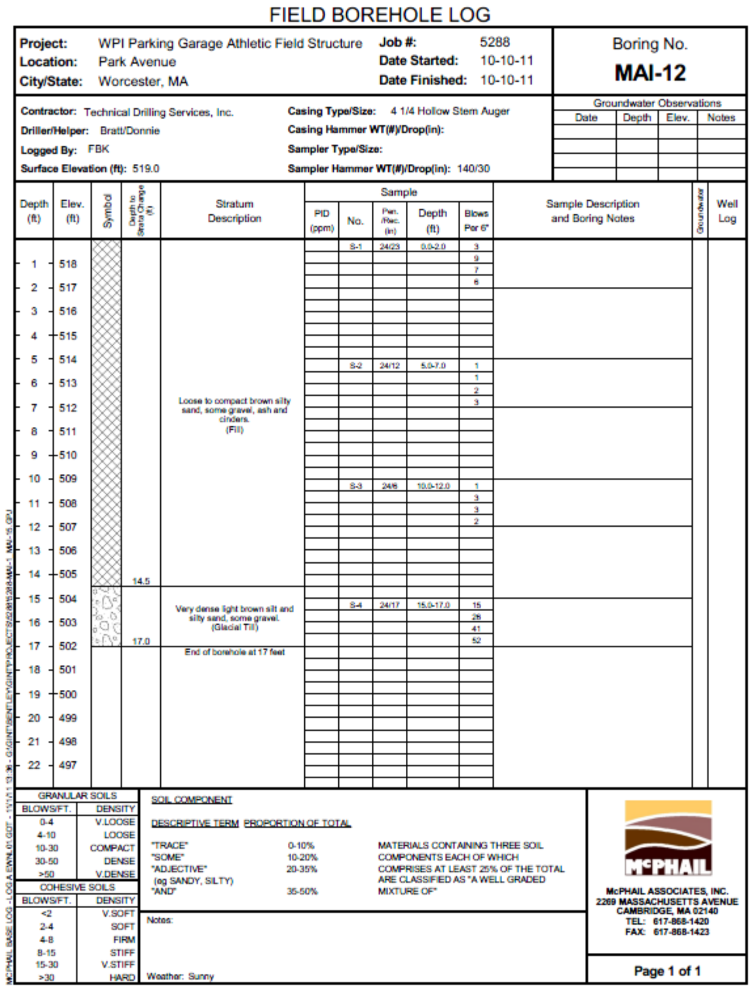

Figure 19: Example of a Borehole Log (McPhail 2012)

In addition to the groundwater results from the test pits and boreholes a groundwater observation well was set up in one of the boreholes groundwater was encountered. After a period of time the well was checked to determine the groundwater considerations for the site. Since water affects how well soil can support stress and structures it is important to determine if groundwater will play a role on this site. Groundwater also affects a variety of construction activities, such as excavation.

4.1.2 Representative Soil Profile

Using the findings of construction and the information from the Soil Report it is then possible to determine the soil profile of the site. Taking cross-sections of the site, 4 length-wise and 4 width-wise, to better understand the layout of the soil. These cross-sections can be used to extrapolate where soil layers change depth thus allowing a more detailed picture of the ground conditions.

The nature of this project allows us to look at the soil cross-section with more information as the excavation for foundation resulted in information which differed from the Geotechnical report's evaluation of the site. When the foundations were being prepared there were certain foundation locations which proved to have bed rock at a much higher elevation than the report had anticipated. Shown in Figure 20 the blue area is known to have bedrock at a suitable depth for shallow foundation while the green area does not have bedrock within an acceptable range.

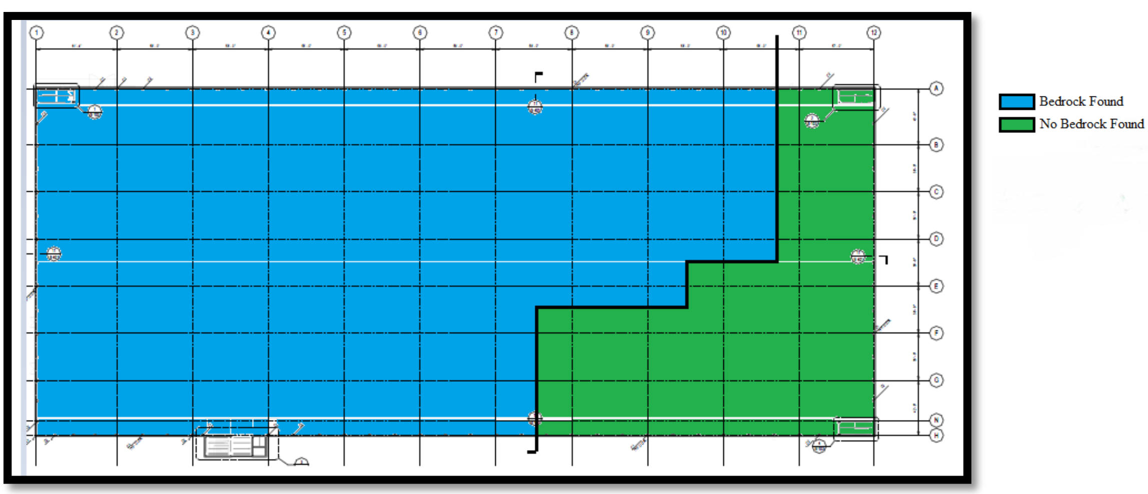

Figure 20: Location of Suitable Bedrock

The change to the bedrock depth information did not affect where the soil properties were developed from. Using the boring logs and test pit logs, examples shown in Figures 18 and 19, the thickness of the different soil layers could be obtained. These tests also gave information about the number of blows for 6 inches of penetration which can then be used to calculate the SPT "N-value" of the soil. N-values are known as the number of blows required for the second and third 6 in penetration; it is also referred to as the standard penetration resistance.

With the information provided in the Soil Report, cross-sectional soil profiles of the site were created (See Appendix for details). These cross-sections were determined with information about the elevation of the soil and the relative depths of each varying soil layer. The cross-sections also took into account the varying distances from each test site, thus each data point has a unique location. These cross-sections made it possible to interpolate what was occurring beneath the surface of the site.

Since the site had already been divided into shallow foundation suitable and deep foundation suitable it was then possible to create a general soil profile schematic for each scenario. Figure 21 shows the representative soil profiles with respect to bedrock within suitable shallow foundation depth.

Figure 21: Average Shallow Soil Profile

For the area, shown in green in Figure 20, which does not have bedrock within shallow foundation suitable depth the representative soil profile is provided in Figure 22.

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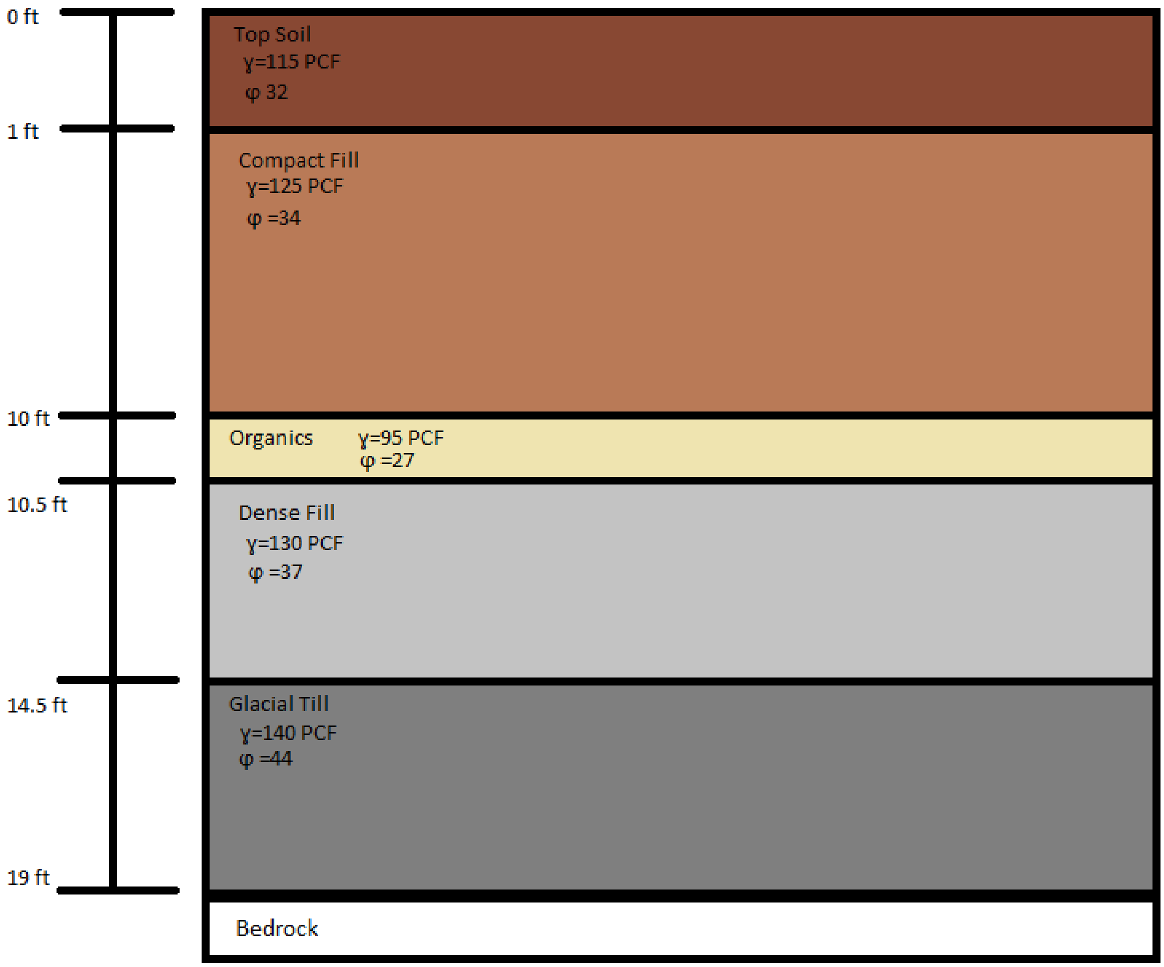

Figure 22: Average Deep Soil Profile

Shown in Figure 20, the layers of soil in the blue area of the site are relatively short (less than 5 ft in thickness) when compared to the soil layers in the green area. These layers are also very similar to each other with a stronger layer of glacial till before ultimately hitting bedrock. This characterization makes shallow foundations a good option as an adequate bearing capacity could be provided from shallow soil layers. Figure 20 however shows that in the green area of the site the layers are larger (greater than 5 ft in thickness) and less consistent, a 9 ft layer of compact fill lays atop a 6 in layer of organics then to be followed by a 4 ft layer of dense fill before reaching glacial till, the presence of bedrock not ensured.

Values are outlined in Table 6 along with other soil characteristics and N values.

Table 6: Soil Properties

Soil Properties							Shallow	Deep
Soil Type	γ lb/ft³	c' lb/ft²	Φ	N_{60}	N	$(N_1)_{60}$	σ' lb/ft²	
Compact Fill	125	0	34	13.75	20	24	177.5	677.5
Topsoil	115	0	32	10.3	15	60	57.5	57.5
Dense Fill	130	0	37	20.6	30	23	500	1547.5
Glacial Till	140	0	45	41.25	60	39	795	2157.5
Organics	95	0	27	3.4	5	4		1263.75

The soil report did lack information about the soil other engineering properties which were then obtained from tables and figures in the Donald Coduto's Foundation Engineering book (Coduto 2006). Based on the descriptions given in the soil report Table 7 was consulted to determine the unit weight of the soil (γ).

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Table 7: Typical Soil Unit Weights (Coduto 2006)

Soil Type and Unified Soil Classification (See Figure 3.3)	Typical Unit Weight, γ — Above Groundwater Table		Typical Unit Weight, γ — Below Groundwater Table	
	(lb/ft^3)	(kN/m^3)	(lb/ft^3)	(kN/m^3)
GP—Poorly-graded gravel	110–130	17.5–20.5	125–140	19.5–22.0
GW—Well-graded gravel	110–140	17.5–22.0	125–150	19.5–23.5
GM—Silty gravel	100–130	16.0–20.5	125–140	19.5–22.0
GC—Clayey gravel	100–130	16.0–20.5	125–140	19.5–22.0
SP—Poorly-graded sand	95–125	15.0–19.5	120–135	19.0–21.0
SW—Well-graded sand	95–135	15.0–21.0	120–145	19.0–23.0
SM—Silty sand	80–135	12.5–21.0	110–140	17.5–22.0
SC—Clayey sand	85–130	13.5–20.5	110–135	17.5–21.0
ML—Low plasticity silt	75–110	11.5–17.5	80–130	12.5–20.5
MH—High plasticity silt	75–110	11.5–17.5	75–130	11.5–20.5
CL—Low plasticity clay	80–110	12.5–17.5	75–130	11.5–20.5
CH—High plasticity clay	80–110	12.5–17.5	70–125	11.0–19.5

The next important soil property is the internal friction angle (Φ'). These values were interpolated from Figure 21. This figure uses SPT N values and effective vertical stress to find a value for effective friction angle.

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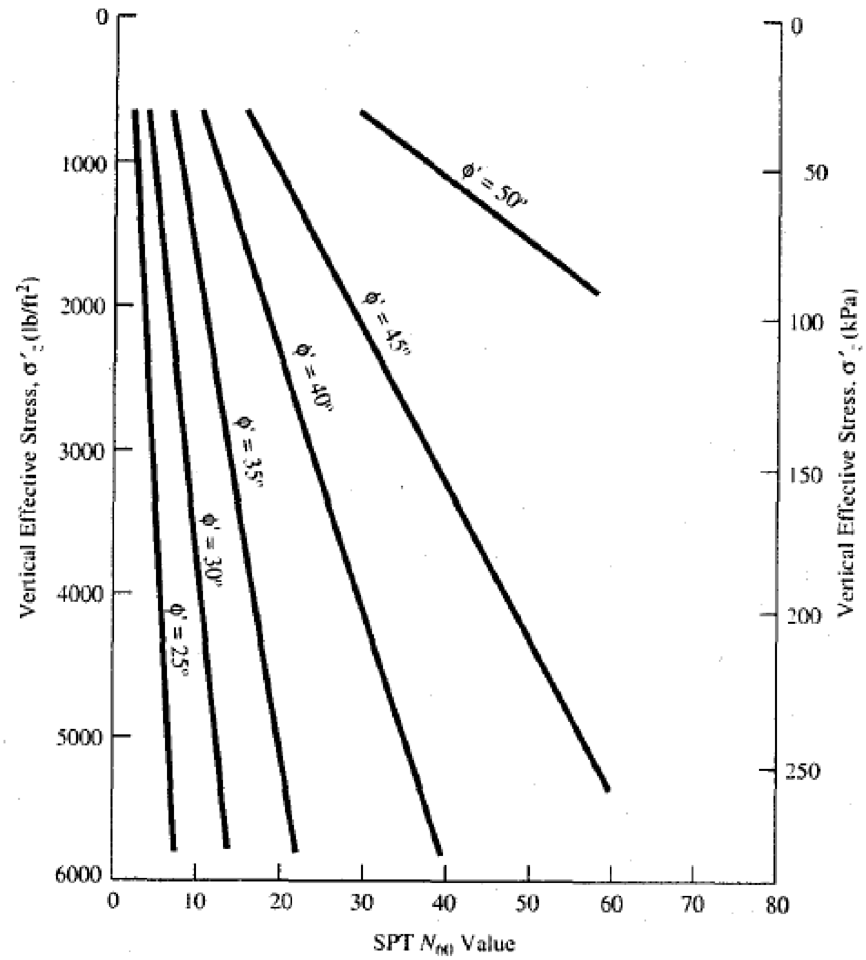


Figure 21: Empirical correlation of SPT value and Internal Friction Angle (Coduto 2006)

4.2 Building Load

Calculating the building loads based on materials used, size of building, and live loads. Once general loads such as dead load, live load, wind load etc. are calculated these loads can be used with the Load and Resistance Factor Design method. This method gives equations with loading factors to determine the most critical combined loading, this method also applies strength reduction factors and such that the factored strength must be greater than or equal to the factored load. This method is more accurate in ensuring adequate strength for various loading situations as it does not use one global factor of safety but rather separates the different parts of loading design.

This project is unique in the way loading is calculated due to the fact that the foundation of the building is primarily holding the load from the second story and all the support structure and the first floor does not require foundation design. To determine the loads on the foundation it is first necessary to follow the American Society of Civil Engineers Standard to quantify the live load. According to the standard live loads for the stairwell's are 100psf and the field also has a live load of 100psf. Since these two values correspond it is not necessary to differentiate whether the column is supporting the field or the stairwell when calculating column varying column loads.

Dead loads for the building (self-weight), were calculated in sections of girders, double tees, and gravel and then added together to find the total. The double tee weights can be found in the Precast Concrete Institute Standards which is 62.62psf based on the fact that the span of the beams is between 55 and 60ft. The weight of gravel is calculated using the average thickness of gravel on the field and a unit weight of 105lb/ft^3.

Equation 8: Gravel Weight

$$Gravel\ Weight = \frac{6in + 11in}{2} \times \frac{ft}{12in} \times 105lb/ft^3$$

$$= 74.37lb/ft^2$$

Finally the girder weight can also be obtained from the Precast Concrete Institute Manual which makes the selection of two types of members, one for long spans and another for short spans. In this way the total weight of the girders is calculated then added together before being divided by the structure's total area (172604ft^2).

Equation 9: Long Span Weight

$$Weight_{24IT48} = 5510ft \times 800lb/ft \times \frac{1K}{1000lb}$$

$= 4168\ Kip$ (9)

Equation 10: Short Span Weight

$$Weight_{24IT40} = 3180ft \times 700lb/ft \times \frac{1\ K}{1000lb}$$

$= 2226\ Kip$ (10)

Equation 11: Total Girder Weight

$$Weight_{total} = 4168K + 2226K = 6394K$$

$\frac{6394K \times \frac{1000lb}{1K}}{172604ft^2} = 37.04psf$ (11)

Dead load then combines those calculations to achieve

Equation 12: Dead Load

$$DL = 62.62psf + 37.04psf + 74.37psf = 174.03psf$$

The Massachusetts Building Code also has snow, wind, and seismic loads that must be accounted for. For snow load the information can be found in a table (5301.2) after first determining the terrain category (0.9), thermal factor unheated structures (1.2), and importance factors (1.0). The snow load was found to be 33psf. The wind load is determined by finding exposure area for winds and then looking at table 1611.4 to obtain a wind load value of 11psf. Seismic load calculations are slightly more laborious as the calculations for dead load must already be completed.

Equation 13: Earthquake Load

$$E = Q_E + 0.2S_{DS}D$$

Where, E=Earthquake load
S_{DS}=2/3(F_aS_s)
Q_E=1.97xPressure of Roof
D=Dead load
F_a=1.2
S_s=0.24

This calculation provides the value of 130.2psf for seismic load.

Now that the general loading calculations are complete it is time to determine which load combination, by the Load and Resistance Factor Design Method, governs the structure.

Table 8: Ultimate Loading Equations

U=1.4D	243.64 psf
U=1.2D+1.6L+0.5S	385.34 psf
U=1.2D+1.6W+0.5L+0.5S	292.94 psf
U=1.2D+1.6S+(0.5L or 0.8W)	311.64 psf
U=0.9D+(1.6W or 1.0E)	287.34 psf

In this instance the second load combination is the highest value so to ensure most safe design that value should be used.

To determine the load on a particular column the particular sections acting on that column must be determined. The area between columns is split into four sections, using the bisecting distances of the columns; each of these sections is transferring their load to a different column. As shown in Figure 24, columns do not all carry the same amount of the load due to how the load is spread throughout the structure

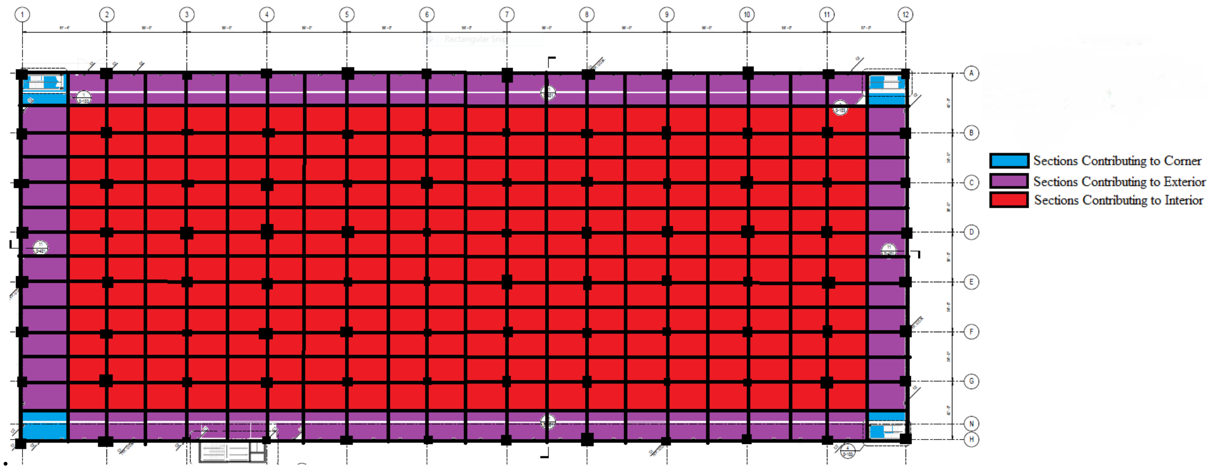


Figure 22: Load Distribution

From the figure it is clear that there are three different regions of load-to-column distribution. The blue areas show columns which are only receiving one section of the structure load, while purple and red are receiving 2 and 4 respectively. The sections are roughly the same size and load, yet due to the layout of columns the exterior columns will transfer less weight to the foundation.

To determine the weight each column is transferring, the area of each column will be taken as the middle distance between each column and the neighboring column. These areas are then checked with the governing load combinations to determine the foundation load. Details about each individual column can be found in the attached Excel file. From this load calculation the loads for the three types of areas are as follows: Corner Columns 255K, Exterior columns 480K, and Interior columns 908K.

4.3 Shallow Foundation

Shallow foundations are commonly used foundation types as this type is typically sufficient for non-major structures as well as being more cost efficient than deep foundations. Shallow foundations work by transferring the load of the structure to the directly underlying soil. Types of shallow foundation are slab on grade, mat foundation, and spread footings. Determination on type of shallow foundation is based on settlement calculations and overall area of foundation. Shallow foundations are chosen when ground conditions have been determined to support the load without too much settlement. (Day)

4.3.1 Soil Bearing Capacity

Using the previously determined soil profile to find areas where shallow or deep foundation is more applicable. Using the soil properties determined for the soil profile the bearing capacities of the soil can be determined by the Terzaghi method (Coduto, 176).

Equation 14: Terzaghi bearing capacity equations based on shape

$$q_{ult} = 1.3c'N_c + \sigma'_{zD}N_q + 0.4\gamma'BN_\gamma \quad (for\ square\ foundations)$$

$$q_{ult} = c'N_c + \sigma'_{zD}N_q + 0.5\gamma'BN_\gamma \quad (for\ continuous\ foundations)$$

$$q_{ult} = 1.3c'N_c + \sigma'_{zD}N_q + 0.3\gamma'BN_\gamma \quad (for\ circular\ foundations))$$

Where, N_c, N_q, N_γ = Terzaghi's bearing capacity factors (calculated based on internal friction angle)

The Terzaghi bearing capacity formula can be applied to find the ultimate capacity in relation to size and shape of foundation. Values for soil types to be based on tests done for the geotechnical report, boreholes and sieve analysis and are used in the Terzaghi method by substituting the friction angle for the base soil type into the bearing capacity factors equations. A schematic of the geometry of the Terzaghi failure surface from which the bearing capacity formulas are derived is below (Figure 23.)

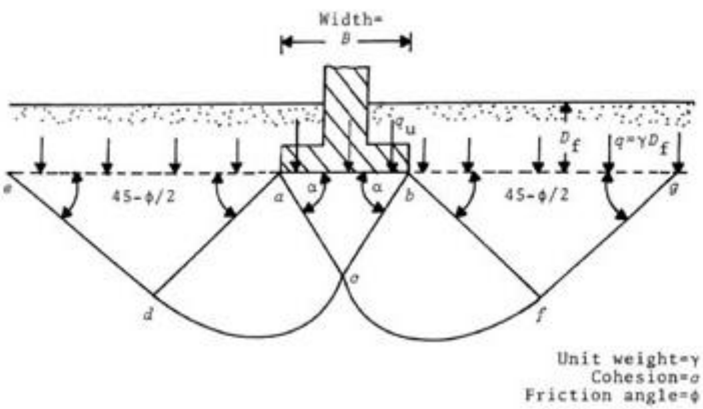


Figure 23: Terzaghi Failure Surface (Globospec 2012)

Settlement of the soil and compressibility will also be calculated. Settlement will be calculated using Schmertmann's Method (Coduto 2006).

Equation 15: Schmertmann's Method

$$\delta = \frac{C_1C_2C_3(q - \sigma'_{zD})\left(I_{ep} + 0.025\right)B}{E_s}$$

Where, C_1, C_2, C_3= are correction factors
I= peak strain influence factor
E_s= Modulus of Elasticity

Equation 16: Modulus of Elasticity

$$E_s = \beta_0\sqrt{OCR} + \beta_1 N_{60}$$

$E_s = equivalent\ modulus\ of\ elasticity$
$\beta_0, \beta_1 = correlation\ factors\ from\ Table$
$OCR = overconsolidation\ ratio$
$N_{60} = SPT\ N - value\ corrected\ for\ field\ procedures$

This method takes into account the depth of the soil, the creep, and also the shape of the foundation. This settlement calculation requires information on stiffness found from the SPT and CPT tests, which will have been calculated for the representative soil profile. This method also requires the value for vertical effective stress which is based on the soil depth and weight, both of which can be found from the soil profile.

To determine the size of a shallow foundation creating a Bearing Capacity Chart is an ideal step. The bearing capacity chart shows the bearing capacity of the soil as a function of foundation size along with settlement functions with which an appropriate settlement amount can be chosen for the project. Figure 24 shows the bearing capacity chart for the project.

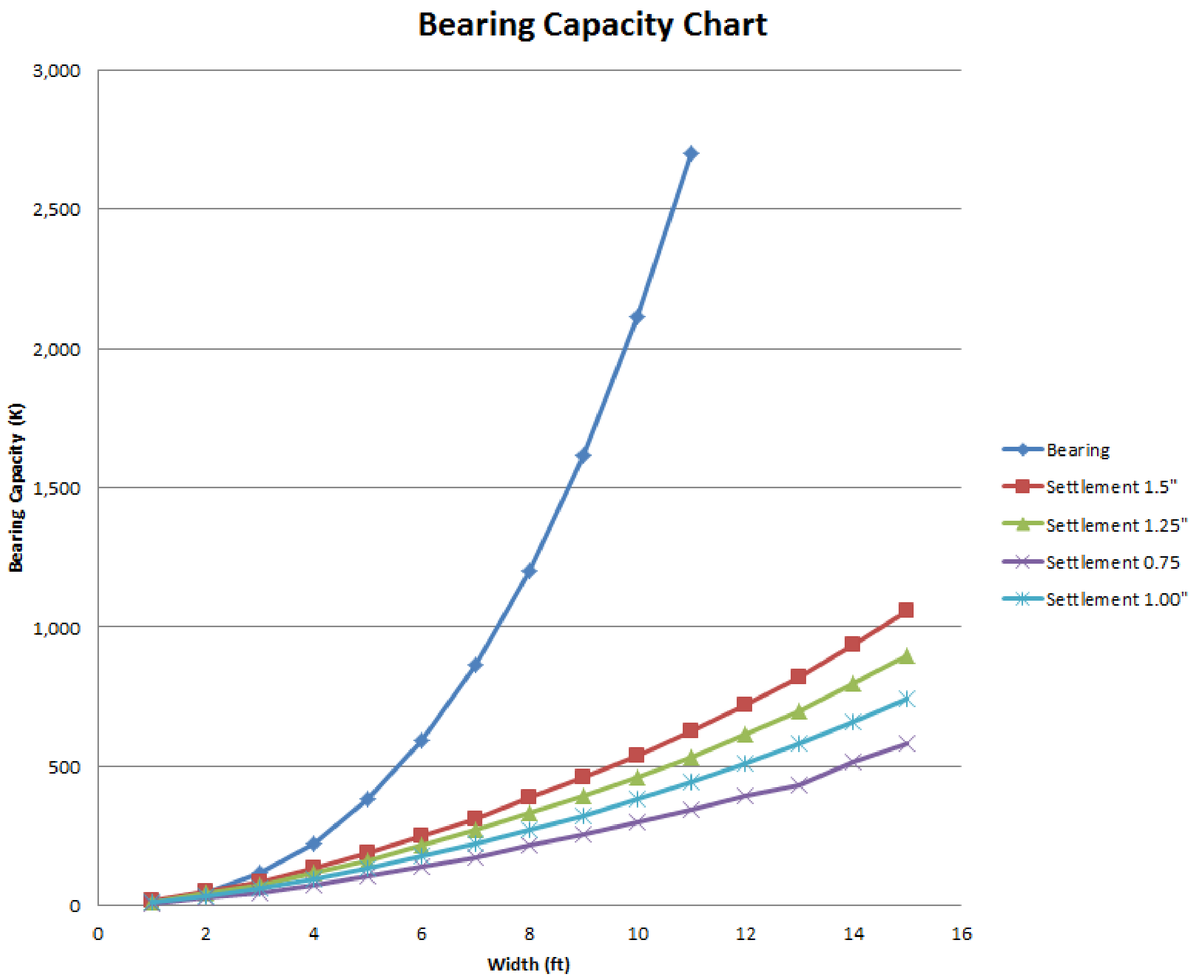
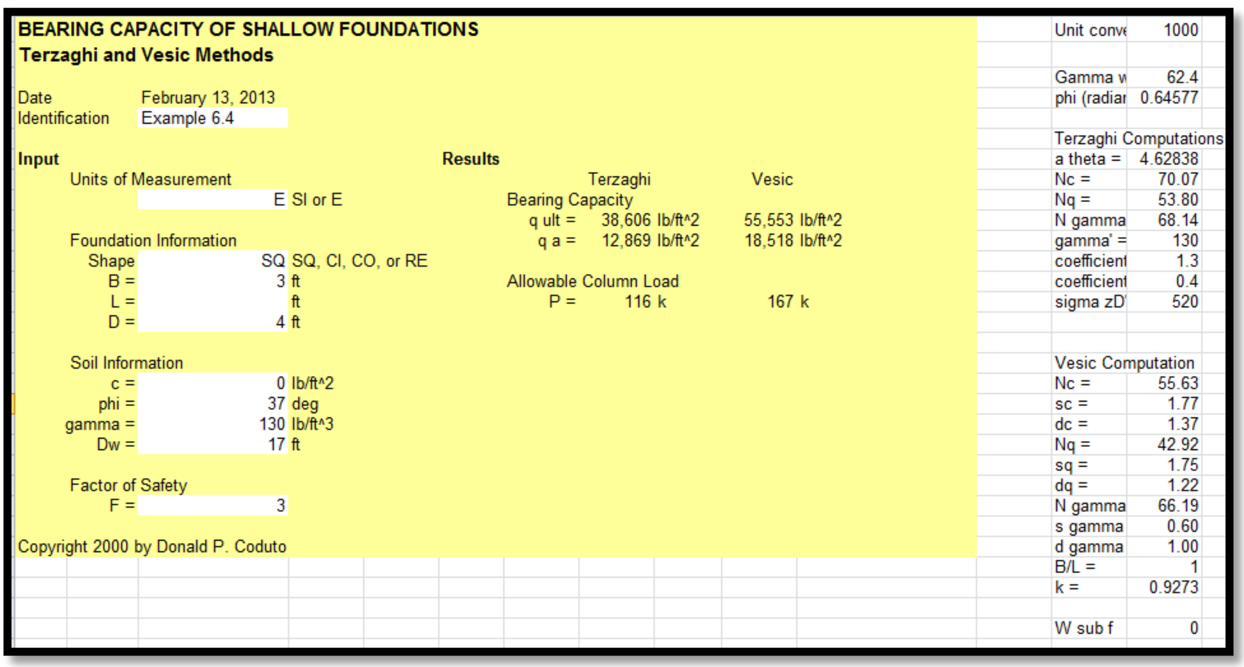


Figure 24: Bearing Capacity Chart

This chart was created using the Terzaghi method for bearing capacity. Using an Excel spreadsheet which requires the ϕ, ɣ, and depth of water table the spreadsheet calculates the Terzaghi coefficients which allow the user to input possible footing sizes and the spreadsheet gives the resulting allowable column load. These values are the soil properties of the soil layer that the bottom of the foundation will be sitting on, values found in Table 1. The factor of safety chosen was 3 and an embedment depth of 4 ft was also used in the spreadsheet. An example of this spreadsheet filled in can be seen in Figure 27.



BEARING CAPACITY OF SHALLOW FOUNDATIONS
Terzaghi and Vesic Methods

Date	February 13, 2013					
Identification	Example 6.4					
Input			**Results**			
Units of Measurement				Terzaghi	Vesic	
	E	SI or E	Bearing Capacity			
			q ult =	38,606 lb/ft^2	55,553 lb/ft^2	
Foundation Information			q a =	12,869 lb/ft^2	18,518 lb/ft^2	
Shape	SQ	SQ, CI, CO, or RE				
B =	3	ft	Allowable Column Load			
L =		ft	P =	116 k	167 k	
D =	4	ft				
Soil Information						
c =	0	lb/ft^2				
phi =	37	deg				
gamma =	130	lb/ft^3				
Dw =	17	ft				
Factor of Safety						
F =	3					

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Unit conve	1000
Gamma w	62.4
phi (radiar	0.64577
Terzaghi Computations	
a theta =	4.62838
Nc =	70.07
Nq =	53.80
N gamma	68.14
gamma' =	130
coefficient	1.3
coefficient	0.4
sigma zD'	520
Vesic Computation	
Nc =	55.63
sc =	1.77
dc =	1.37
Nq =	42.92
sq =	1.75
dq =	1.22
N gamma	66.19
s gamma	0.60
d gamma	1.00
B/L =	1
k =	0.9273
W sub f	0

Figure 27: Bearing Capacity of Shallow Foundations Spreadsheet (Coduto 2000)

Similarly the settlement curves were found. Important values for the spreadsheet were calculated using the method stated above, and then inputted into the spreadsheet to create functions with different settlement results based on the applied load and the size of the footing. Figure 28 shows an example of the Settlement curve with appropriate values. Since settlement is partially determined by the Equivalent Modulus of Elasticity, the values change as the depth of the soil layer increases as each type of soil has different characteristics that go into the calculation.

SETTLEMENT ANALYSIS OF SHALLOW FOUNDATIONS
Schmertmann Method

Date	February 13, 2013
Identification	Example 7.6

Input			Results		
Units	E	E or SI			
Shape	SQ	SQ, CI, CO, or RE	q =	4636	lb/ft^2
B =	15	ft	delta =	1.26	in
L =		ft			
D =	4	ft			
P =	908	k			
Dw =	17	ft			
gamma =	130	lb/ft^3			
t =	50	yr			

Depth interval	1			
gamma w	62.4		Units	E
gamma c	150		Shape	SQ
Wf	135000		C1	0.937
uD	0		C2	1.540
sigma zD'	520		C3	1.000
sigma zp' sq	1495			
sigma zp' con	2345.2			
lep square	0.66592			
lep contin	0.63247			
in or mm conv	12			
k or kN conv	1000			

Depth to Soil Layer									
Top (ft)	Bottom (ft)	Es (lb/ft^2)	zf (ft)	I epsilon	strain (%)	delta (in)	zf/B	le square	contin
0.0	4.0								
4.0	5.0	297200	0.5	0.138	0.2751	0.0330	0.033	0.138	0.214
5.0	6.0	297200	1.5	0.213	0.4258	0.0511	0.100	0.213	0.243
6.0	7.0	297200	2.5	0.289	0.5766	0.0692	0.167	0.289	0.272
7.0	8.0	297200	3.5	0.364	0.7273	0.0873	0.233	0.364	0.301
8.0	9.0	545000	4.5	0.440	0.4788	0.0575	0.300	0.440	0.330
9.0	10.0	545000	5.5	0.515	0.5610	0.0673	0.367	0.515	0.359
10.0	11.0	545000	6.5	0.590	0.6432	0.0772	0.433	0.590	0.387
11.0	12.0	545000	7.5	0.666	0.7258	0.0871	0.500	0.666	0.416
12.0	13.0	545000	8.5	0.637	0.6935	0.0832	0.567	0.637	0.445
13.0	14.0	545000	9.5	0.607	0.6612	0.0793	0.633	0.607	0.474
14.0	15.0	545000	10.5	0.577	0.6290	0.0755	0.700	0.577	0.503
15.0	16.0	545000	11.5	0.548	0.5967	0.0716	0.767	0.548	0.532
16.0	17.0	545000	12.5	0.518	0.5645	0.0677	0.833	0.518	0.560
17.0	18.0	545000	13.5	0.489	0.5322	0.0639	0.900	0.489	0.589
18.0	19.0	545000	14.5	0.459	0.5000	0.0600	0.967	0.459	0.618
19.0	20.0	545000	15.5	0.429	0.4677	0.0561	1.033	0.429	0.625
20.0	21.0	545000	16.5	0.400	0.4355	0.0523	1.100	0.400	0.611
21.0	22.0	1004900	17.5	0.370	0.2187	0.0262	1.167	0.370	0.597
22.0	23.0	1004900	18.5	0.341	0.2012	0.0241	1.233	0.341	0.583
23.0	24.0	1004900	19.5	0.311	0.1837	0.0220	1.300	0.311	0.569
24.0	25.0	1666700	20.5	0.281	0.1002	0.0120	1.367	0.281	0.555
25.0	26.0	1666700	21.5	0.252	0.0897	0.0108	1.433	0.252	0.541
26.0	27.0	1666700	22.5	0.222	0.0791	0.0095	1.500	0.222	0.527
27.0	28.0	1666700	23.5	0.192	0.0686	0.0082	1.567	0.192	0.512
28.0	29.0	1666700	24.5	0.163	0.0580	0.0070	1.633	0.163	0.498
29.0	30.0	1E+09	25.5	0.133	0.0001	0.0000	1.700	0.133	0.484
30.0	31.0	1E+09	26.5	0.104	0.0001	0.0000	1.767	0.104	0.470
31.0	32.0	1E+09	27.5	0.074	0.0000	0.0000	1.833	0.074	0.456
32.0	33.0	1E+09	28.5	0.044	0.0000	0.0000	1.900	0.044	0.442

Figure 25: Settlement Spreadsheet Schmermann Method

Once the column load is calculated, the bearing capacity chart can be consulted to choose a footing size that would be able to hold the load without excess settlement.

4.3.2 Size Calculation

To calculate the footing dimensions the first step is to determine an allowable settlement. For this project an allowable settlement is 1.25 since it is within the usual settlement amounts based on Table 9. Using this determination the loading amounts are then compared to the bearing capacity chart so that square footing sizes can be designed based on the three different loading types, Corner columns, exterior columns, and interior columns.

Table 9: Settlement Amounts (Coduto 2006)

Type of Structure	Typical Allowable Total Settlement, δ_a (in)	(mm)
Office buildings	0.5–2.0 (1.0 is the most common value)	12–50 (25 is the most common value)
Heavy industrial buildings	1.0–3.0	25–75
Bridges	2.0	50

The next dimension to be determined is the thickness of the footing so that the footing can be designed to avoid shear failure.

Design for Shear

A footing thickness of 30in. is chosen for all types of loading to simplify the construction and calculation of the types of foundation. This thickness must then be checked to ensure that it can withstand shear failure using Equation 17.

Equation 17: Shear Load Design

$$V_u \leq (P + W_f)\mu_u + 0.5\lambda_a BD^2$$

Where W_f= weight of the footing
μ_u= allowable coefficient of friction
λ_a= allowable equivalent passive fluid density

The effective depth for the reinforced concrete member is determined by the following equation.

Equation 18: Effective Depth

$$d = T - 3in - d_b$$

d_b is the diameter of the reinforcing bars. In this case we will be using #8 bars which have a diameter of 1in. So the effective depth of the footing is 26in.

Design for Flexure

Then the flexural stress must be calculated. To find the flexural stress the design cantilever distance must be found. For concrete the design cantilever distance is in the following equation.

Equation 19: Design Cantilever Distance

$$l = \frac{B - c}{2}$$

B=width of the footing
c=the column width

The flexural stress is then found using the following equation.

Equation 20: Flexural Stress

$$M_u = \frac{P_u \times l^2}{2B}$$

P_u=the column load

The flexural stress is then used to determine the area of steel needed to reinforce the footing against shear failure. Using the equation for Area of steel and then checked using the minimum steel area, whichever is larger is the governing steel area.

Equation 21: Area of Steel

$$A_s = \frac{F_c' b}{1.176 F_y} \times (d - \sqrt{d^2 - \frac{2.353 M_u}{0.9(F_c')b}})$$

$$A_{smin} = 0.018(d)(B)$$

F'$_c$= compressive strength of concrete 4000lb/in^2
F_y=yield strength of steel 60,000lb/in^2

Once the areas of steel are calculated then use that value to calculate how many #8 bars it would take to achieve that steel area given that #8 bars have an area of $0.79in^2$. That is the number of bars needed in each direction and then evenly spaced along the width of the footing.

4.3.3 Results

By analyzing the loads that will be transferred into the footing there were many loads varying throughout the site. This is shown in Figure 12. Since the loads can be categorized there was only one footing design per load group; corner, exterior, and interior. Calculations can be found in Appendix C.

Table 10: Summary of Shallow Foundation Size

Type	Size	Steel
Interior	180x180x30	15 #8 bars
Exterior	124x124x30	8 #8 bars
Corner	82x82x30	5 #8 bars

Table 11: Summary of Load Types

Type	Loads
Interior	908K
Exterior	480k
Corner	255k

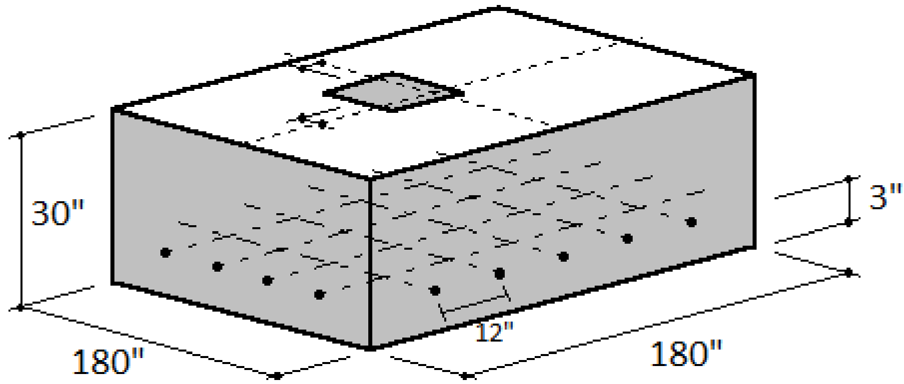

Figure 26: Interior Shallow Foundation Footing

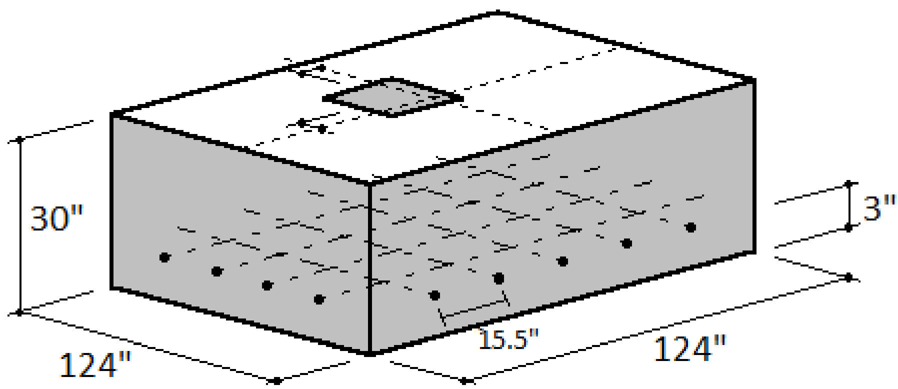

Figure 27: Exterior Shallow Foundation Footing

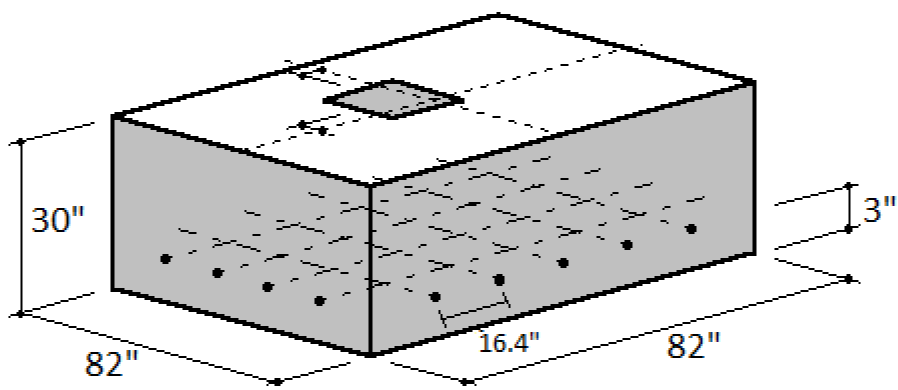

Figure 28: Corner Shallow Foundation Footing

4.5 Deep Foundations

Deep foundations are not as commonly used as shallow foundations; however deep foundations are used in several different situations. Deep foundations can vary greatly depending on the project site as soil and ground conditions must be taken into account. Types of deep foundations are piles, drilled shafts, caissons, Madrel-driven thin shells, Auger-cast piles, pressure-injected footings (PIFs), and anchors. Deep foundations differ from shallow foundations in that the support of the structure load requires more support than the underlying soil near the surface can bear (Day).

As stated earlier, piles are a type of deep foundation. Piles are known as prefabricated members which are then forced into the underlying soil using some sort of driving mechanism (Coduto 2006). Unlike driven piles, drilled shafts are formed by drilling a hole into the ground where reinforcing steel is inserted and then concrete is poured into the hole. Caissons are similar to drilled shafts in the fact that concrete is poured after the space is created, yet there is no hole drilled and a prefabricated box or enclosure is sunk into the ground for the concrete to be poured into (Coduto 2006). Mandrel-driven thin shells are filled with concrete after the shell has been driven into the ground; this is similar to the previously explained deep foundation types. Auger-cast piles are constructed similarly to drilled shafts yet the resulting hole is filled with grout using the tool called the auger. Pressure-injected footings (PIF) are constructed in a way similar to piles, as the foundation is forced into the soil using a driving mechanism such as a drop hammer yet instead of a prefabricated member, PIFs are made using cast-in-place concrete. Anchors are a type of deep foundation which encompasses several different kinds of foundation and are designed specifically to resist uplift situations. Anchors have varying shapes such as enlarged bases which resist the uplifting forces (376). The following Table describes the different benefits and negative aspects of each outlined deep foundation type.

Table 12: Deep Foundation Benefits vs. Negatives

Deep Foundation Type	Positives	Negatives
Piles	• Maintain shape when installed • Variety of materials (cost effective) • Can be driven vertically or at an angle	• Very dependent on type of soil • Can be disruptive due to installation
Drilled Shaft	• Not very noisy, good for sound sensitive sites • Can penetrate soil with boulders	• Removed soil must be disposed of • Does not consolidate underlying soil could result in lower end bearing capacity
Caissons	• Beneficial for bridge design	• Often not economical
Mandel-driven thin shells	• Materials can be shipped to site in pieces, easy to build long piles	• Necessary to have a pile driver and other equipment • Cost in at least the same as driven piles/no cost benefit
Auger-cast piles	• Minimal disturbance (used for noise and environmentally sensitive areas • Can be used in soils which may not be able to use driven piles or drilled shafts	• Not suited for contaminated soils • Not well suited in grounds with obstructions such as boulders • Relies heavily on equipment (sensitive to breakdowns)
PIFs	• Compacted soil has a higher load bearing capacity • Possible to have a large base	• Construction equipment is bulky and cumbersome • Economical only when less than 30 ft. deep
Anchors	• Cost efficient uplift force resistance	• Not always necessary since most deep foundation resists some uplift forces

The differences between deep and shallow foundations are particularly important to this project due to the nature of the soil. The soil conditions for this site vary considerably, which is why both types of foundation are to be considered. At the western side of the site (shown below in Figure 32.), closest to the football field, the soil conditions have suitable bedrock within 10 to 15 feet below the ground surface. At the opposing end of the site the bedrock level is not reached until at least 20 feet below the surface. The bedrock at this site is noted to be highly fractured and the intermittent soil is classified as "Urban Fill" which is susceptible to settling over time. While the structure is uniformly distributed over the site, often meaning one type of foundation can be used, the nature of the soil at this site favors a combination of deep and shallow foundation. The structure is made up of heavy concrete that could cause drastic settlement if only shallow foundations are used. If settlement were to occur on this site there would be major concerns with the integrity of the structure since damage to the concrete could occur. Foundation types must be chosen to ensure the least amount of settlement so no point of the structure is drastically changed.

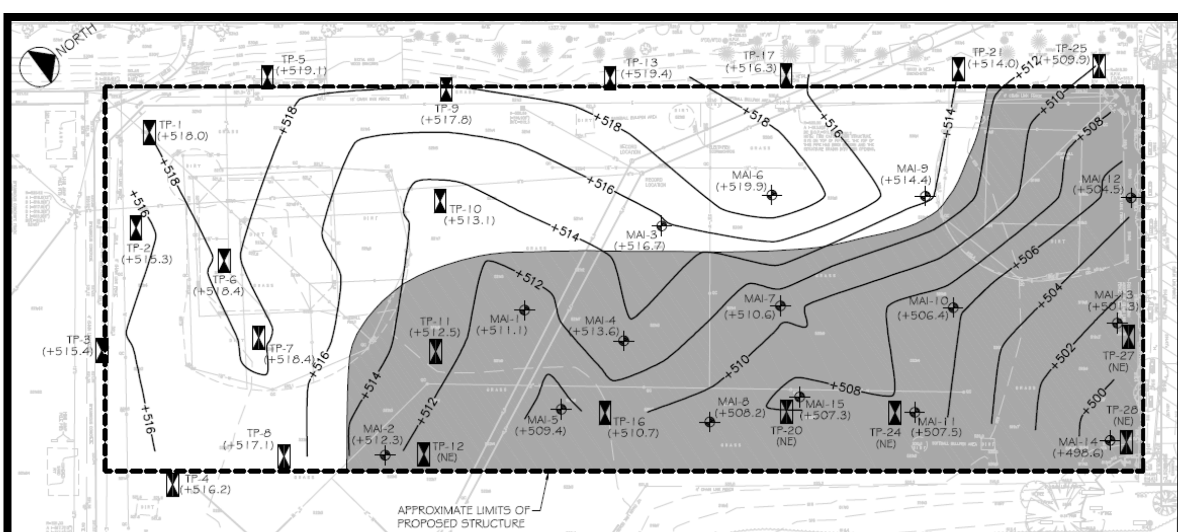

Figure 29: Site Profile including Soil Test Locations (McPhail 2012)

4.5.1 Size Calculation

Dimensions for the deep foundation design could not be determined from the bearing capacity chart since the chart is created using bearing and settlement methods which only work for shallow foundations. To find the deep foundation dimensions it is first important to choose a type of foundation as the equations for deep foundation design are often particular to the type of foundation. For this site PIF's are the preferred deep foundation type since, according to section 4.3 the depth of PIF is to be less than 30ft and the compacted soil allows for a stronger foundation. Overall the equation for downward loading capacity of piles is in the following equation.

Equation 22: Loading Capacity of Piles

$$P_{ult} = \frac{q_t' A_t + \sum f_s A_s}{F}$$

P_{ult}=factored downward load capacity
q_t'=toe-bearing resistance
A_t=area of toe-bearing contact
f_s=side-friction resistance
A_s=area of side-friction contact
F=factor of safety

According to this formula it is then necessary to find the side friction resistance of each soil layer. To determine f_s the following equation was used.

Equation 23: Side Friction Resistance

$$\boldsymbol{f_s = K_0 \sigma_z' \left(\frac{K}{K_0}\right)\left(\frac{\varphi_f}{\varphi'}\right)}$$

K_0=lateral earth pressure
σ=vertical effective stress
K/K_0=ratio of coefficient of lateral earth pressure (found in table 10)
φ/φ=found in table 14.4

Table 13: φ/φ' Values for Deep Foundations (Coduto 2006)

Foundation Type	ϕ_f/ϕ'
Rough concrete	1.0
Smooth concrete (i.e., precast pile)	0.8–1.0
Rough steel (i.e., step-taper pile)	0.7–0.9
Smooth steel (i.e., pipe pile or H-pile)	0.5–0.7
Wood (i.e., timber pile)	0.8–0.9
Drilled shaft built using dry method or with temporary casing and good construction techniques	1.0
Drilled shaft built with slurry method (higher values correspond to more careful construction methods)	0.8–1.0

Table 14: Ratio of Coefficient of Lateral Earth Pressure (Coduto 2006)

Foundation Type and Method of Construction	K/K_0
Pile—jetted	0.5–0.7
Pile—small displacement, driven	0.7–1.2
Pile—large displacement, driven	1.0–2.0
Drilled shaft—built using dry method with minimal sidewall disturbance and prompt concreting	0.9–1.0
Drilled shaft—slurry construction with good workmanship	0.9–1.0
Drilled shaft—slurry construction with poor workmanship	0.6–0.7
Drilled shaft—casing method below water table	0.7–0.9

To find the side friction resistance the effective vertical stress must first be found. This is done by finding the midpoint of each soil layer and calculating the weight of the soil above this point. This can be done using the information found in Figure 11.

To determine the toe-bearing resistance a depth of foundation must be chosen since the toe-bearing resistance is only for the soil layer at the base of the foundation pile. For this site the foundation depth was designed so the toe-resistance would be in the Glacial Till layer. The toe-bearing resistance was then calculated using Nealy empirical formula for PIF's.

Equation 24: Toe-bearing Resistance

$$q_t' = 560(N_1)_{60}\frac{D}{B_b}$$

$(N_1)_{60}$=adjusted N-value
D=depth of pile
B_b=diameter of PIF base

These values are then put into the loading capacity equation to find the diameter of the PIF. The calculated diameter is then used to ensure that the settlement is acceptable using the following equation.

Equation 25: Deep Foundation Settlement

$$\delta = \frac{Pz_x}{AE}$$

P=load
z_x=0.75D
A=area of foundation
E=57000 [(f'$_c$)^0.5]

4.5.2 Results

Similar to shallow foundation, the deep foundation loading was analyzed however the loads were only grouped into two groups for deep foundation. The interior remained its own group yet the exterior and corner groups were merged to simplify construction needs, the more conservative exterior load was used for calculations. Calculations can be found in Appendix C.

Table 15: Summary of Deep Foundation Dimensions

Type	Depth (ft)	Diameter (in)	#of Piles
Interior	17	55	4
Exterior+Corner	17	19.4	4

4.6 As-Built Foundation Analysis

Our foundation designs were based on the soil reports which included boring reports of the estimated soil conditions. Structural designs are typically created before the excavation has begun and then can be altered once a better depiction of the soil conditions for the foundation is discovered. Comparing the as-built foundation design to our calculated design incorporated two main objectives for consideration: overall quantities and cost. Furthermore, the foundation is also broken down between shallow and deep foundations. Tables 16 and 17 below respectively show the differences between calculated and as-built construction foundation sizes with steel and concrete quantities for shallow and deep foundation designs. The calculated foundation design shows a much more conservative foundation. This accounts for an extended durability, higher factors of safety. Also, our design focuses on the most effective foundation design without typical cost constraints.

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Table 16: Shallow Foundation Comparison

Type of Footing	Dimensions (ft)	Quantity	Concrete Quantity (CY)
Calculated Interior	15x15x2.5	47	979.17
Calculated Exterior	10.33x10.33x2.5	21	217.58
Calculated Corner	6.83x6.83x2.5	2	8.64
Total Calculated		71	1205.39
As-Built Foundation 1	9x9x4	12	144
As-Built Foundation 2	10x10x4	24	355.56
As-Built Foundation 3	13.5x8x4	6	96
As-Built Foundation 4	7x7x4	1	7.26
As-Built Foundation 5	6x6x8	3	32
As-Built Foundation 6	7.5x7.5x8	4	66.67
As-Built Foundation 7	6.5x6.5x8	3	37.56
As-Built Foundation 8	13.5x6x8	5	120
Total As-Built		58	859.04

Table 17: Deep Foundation Comparison

Type of Footing	Depth (ft)	Diameter (in)	Quantity of Piles in Footing	Quantity of Footing	Concrete Quantity (CY)
Calculated Interior	17.00	55.00	4	13	34.42
Calculated Exterior	17.00	19.40	4	13	4.28
Total Calculated				26	38.71
As-Built Foundation 9	Varies	20.00	4	14	81.45
As-Built Foundation 10	Varies	20.00	3	13	56.715
As-Built Foundation 11	Varies	16.00	4	10	7.23
Total As-Built				37	96.93

Finding the cost of the as-built foundation footings has been completed by looking at the overall cost of the foundation and comparing that cost to the cubic yardage of concrete. This factor also takes in the assumption that both the designed and as-built structures have the same concrete to steel ratio. Below, Table 18 shows the cost comparison between our designs and the actual construction costs.

Table 18: Cost Comparison of Footings

Type of Foundation Design	Total Footing Yardage	Total Cost	Footing Cost per Yard
As-Built Footings	1004.44	$260,399.00	$259.24
Calculated Footings	1244.10	$322,530.40	$259.24

Using the same cost per unit, the as-built foundation was the more economical choice for this project. The calculated footings were designed for more drastic conditions that what was actually needed. We were able to calculate the cost per cubic yard of the footing and then find the unit cost for the actual construction. Once this was determined, we were able to backtrack the total cost of our designed footings.

5.0 Conclusions and Recommendations

This study concentrated in two major areas: Project management considerations and the use of Building Information Modeling and the design of shallow and deep foundations for the parking structure.

5.1 Project Management

1) Project Scheduling
   a) Project scheduling needs open lines of communication between the CM, Owner, Architects and subcontractors. Receiving input, such as a card trick meeting, is important to having realistic expectations of the project schedule.
   b) Project Schedules typically change due to unforeseen circumstances such as in-climate weather and changes in site conditions. Critical path schedules are extremely important and challenging to keep accurate. Adding float to the original schedule will help insure the project remains on track.
2) Cost Estimating
   a) Project costs often escalate beyond the original expected value. Adding contingencies help cover changes in the project costs. The overall GMP increased throughout this project because of changes in the design and inclement weather that restricted construction progress.
   b) The lazy-s curve helps estimate the overall cost of the project. The preconstruction project costs were minimal compared to the overall project. Once construction began, there was a steep incline in the cost of the project over time. Once the majority of the heavy construction was completed, the project costs leveled out again.
3) Building Information Modeling

a) BIM is a great way to visualize different design options. These models should be used more often in design-build projects to help the client understand what the different options will look like instead of trying to image them. This should also be used more to help improve communication on how the project will look.

b) BIM can be used as a way to check estimates by viewing the material quantities that can be generated in the model.

c) BIM can track the project milestones in phases to help foresee the progress of the project throughout construction.

5.2 Foundation Design

1) Soil Analysis

   a) Boring reports provide an approximation of the overall soil analysis but are not always accurate.

   b) As seen in this project, a small area of land may have a variety of soil capacities.

2) Foundation Design

   a) Soil bearing capacity is a main factor in determining the foundation and footing requirements. Lower soil bearing capacities require deeper and larger footings.

   b) Shallow and deep foundation footings behave differently under different conditions, therefore it is recommended to use a consistent foundation footing type to avoid future damage to the building under stressed conditions.

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Appendix A: Basic Definitions for Construction Management Scheduling

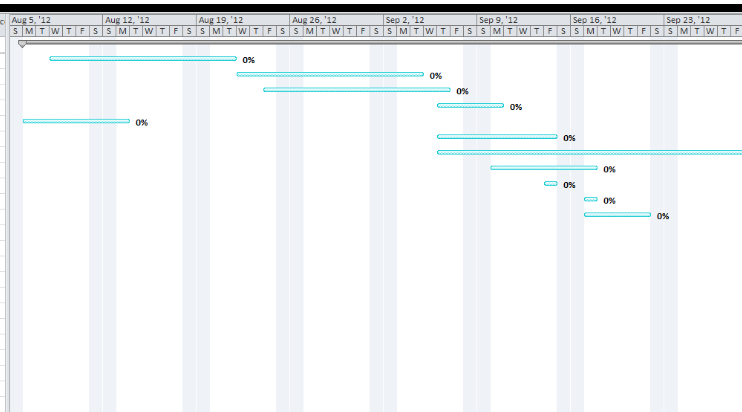
Duration (D)	–	The estimated time required to perform an activity. The time should include all resources that are assigned to the activity.
Early Start (ES)	–	The earliest time an activity can be started.
Early Finish (EF)	–	The earliest time an activity can be finished and is equal to the early start plus the duration $EF = ES + D$
Late Finish (LF)	–	The latest time an activity can be finished.
Late Start (LS)	–	The latest time an activity can be started without delaying the completion date of the project. $LS = LF – D$
Total Float (TF)	–	The amount of time an activity may be delayed without delaying the completion date of the project. $TF = LF – EF = LS - ES$
Free Float (FF)	–	The amount of time an activity may be delayed without delaying the early start time of the immediately following activity. $FF_i = ES_j – EF_i$ Where the subscript *i* represents the preceding activity and the subscript *j* represents the following activity.
Critical Path	–	A series of interconnected activities through the network diagram, with each activity having zero, free and total float time. The critical path determines the minimum time to complete the project.
Dummy Activity	–	An activity (represented by a dotted line on the arrow network diagram) that indicates that any activity following the dummy cannot be started until the activity or activities preceding the dummy are completed. The dummy does not require any time.
Oberlender 2000 - Figure 8-1 Basic Definitions for CPM, P.145		

Appendix B: Schedule Breakdown

Task Name	Duration	Start	Finish
EXCAVATION, SHEETING & SITEWORK	98 days	Mon 8/6/12	Wed 12/19/1
LANDSCAPING	159 days	Tue 8/21/12	Fri 3/29/13
SYNTHETIC TURF	131 days	Mon 7/16/12	Mon 1/14/13
CONCRETE FOUNDATION & FLAT WORK	69 days	Fri 9/14/12	Wed 12/19/1
MASONRY & CMU	77 days	Thu 8/9/12	Fri 11/23/12
MISC METALS	105 days	Tue 8/21/12	Mon 1/14/13
WATER & DAMPROOFING	95 days	Wed 7/11/12	Tue 11/20/12
ROOFING	146 days	Wed 7/11/12	Wed 1/30/13
EXTERIOR WINDOW & GLAZING	133 days	Fri 7/20/12	Tue 1/22/13
GENERAL TRADES	133 days	Tue 6/19/12	Thu 12/20/12
ELEVATORS	100 days	Wed 8/1/12	Tue 12/18/12
PLUMBING	151 days	Wed 7/18/12	Wed 2/13/13
ELECTRICAL	124 days	Fri 7/13/12	Wed 1/2/13
SPORTS LIGHTING	89 days	Mon 8/6/12	Thu 12/6/12
PROJECT MILESTONES	20 days	Thu 1/17/13	Wed 2/13/13

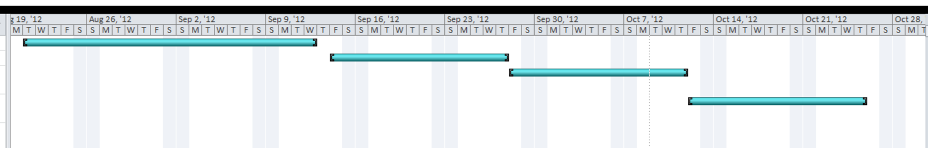
Excavation & Sheeting & Sitework

Task Name	Duration	Start	Finish	Predec
EXCAVATION, SHEETING & SITEWORK	**98 days**	**Mon 8/6/12**	**Wed 12/19/1**	
START EXC / BKFILL INTERIOR SANITARY LINES	10 days	Wed 8/8/12	Tue 8/21/12	
STONE BASE @ UTILITIES ENTIRE FT PRINT	10 days	Wed 8/22/12	Tue 9/4/12	
GRAVEL, GRADE , PAVE Z-1,3,5,6,7,8	10 days	Fri 8/24/12	Thu 9/6/12	
EXCAVATE G.5 UG PLUMBING	3 days	Thu 9/6/12	Mon 9/10/12	
BACKFILL G.5 LINE (SE) 8- 1	6 days	Mon 8/6/12	Mon 8/13/12	
BACKFILL G LINE	7 days	Thu 9/6/12	Fri 9/14/12	
FAB & DEL WOOD GUARD RAIL	17 days	Thu 9/6/12	Fri 9/28/12	
GRAVEL, GRADE , PAVE G.5 SOUTH	6 days	Mon 9/10/12	Mon 9/17/12	
BINDER G.5 LINE 8- 1	1 day	Fri 9/14/12	Fri 9/14/12	
BINDER IN AREA A & B H LINE	1 day	Mon 9/17/12	Mon 9/17/12	
INSTALL WATER LINE @ HILL BY REC CTR	5 days	Mon 9/17/12	Fri 9/21/12	
INSTALL WOOD RAIL @ EAST RD	5 days	Mon 10/1/12	Fri 10/5/12	
INSTALL WATERPROOF PROT BRD @ FIELD 1-4	15 days	Wed 10/24/12	Tue 11/13/12	
RETAINING WALL @ STREET	10 days	Tue 10/30/12	Mon 11/12/12	
START CURBS TOP COAT & WHEEL STOPS IN AREA A &	10 days	Wed 10/31/12	Tue 11/13/12	
INSTALL TRENCH DRAIN @ FIELD 1- 4	12 days	Wed 10/31/12	Thu 11/15/12	
INSTALL STONE @ FIELD 1-4	10 days	Wed 11/7/12	Tue 11/20/12	
SET SAND & CLAY SOFTBALL INFIELD 1-4	15 days	Wed 11/7/12	Tue 11/27/12	
START CURBS TOP COAT ACCESS RD & CUL-DE-SAC	10 days	Thu 11/15/12	Wed 11/28/12	
INSTALL WATERPROOF PROT BRD @ FIELD 5-8	11 days	Thu 11/15/12	Thu 11/29/12	
INSTALL STONE @ FIELD 5 - 8	10 days	Thu 11/22/12	Wed 12/5/12	
INSTALL TRENCH DRAIN @ FIELD 5 - 8	13 days	Mon 12/3/12	Wed 12/19/12	
LINE & STRIPE PARKING	5 days	Fri 12/7/12	Thu 12/13/12	

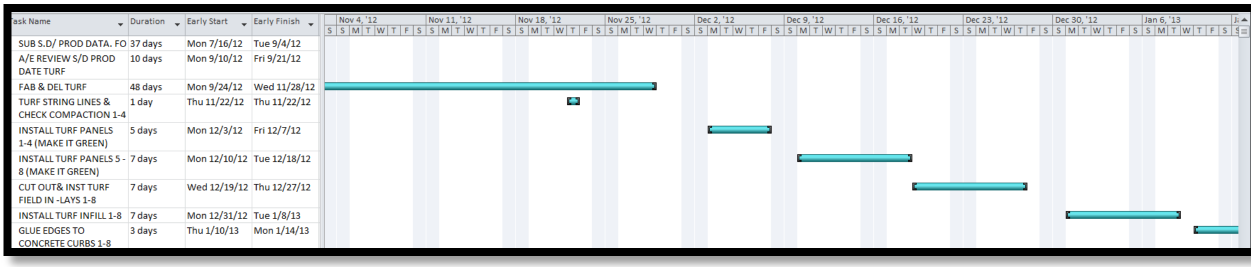


Landscaping

Task Name	Duration	Start	Finish
REECEIVE BIDS LANDSCAI	17 days	Tue 8/21/12	Wed 9/12/12
AWARD LANDSCAPING	10 days	Fri 9/14/12	Thu 9/27/12
SUB S.D. / PD LANDSCAPING	10 days	Fri 9/28/12	Thu 10/11/12
A/E REVIEW SD / PD LANDSCAPING	10 days	Fri 10/12/12	Thu 10/25/12
FAB & DEL LANDSCAPING (SPRING	5 days	Mon 3/25/13	Fri 3/29/13

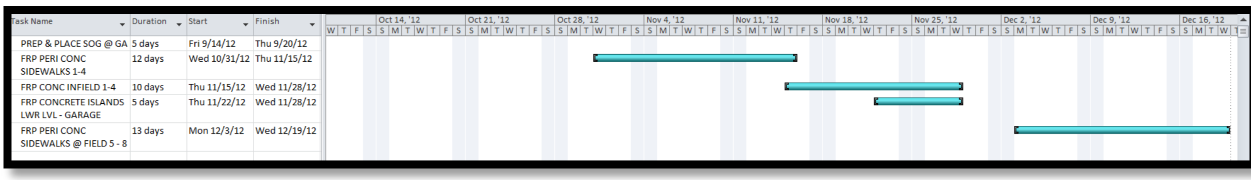


Synthetic Turf



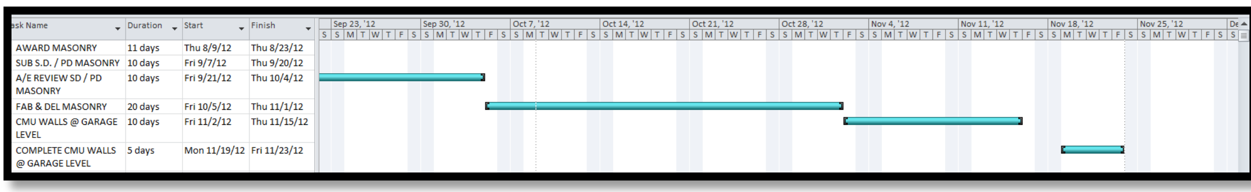
Task Name	Duration	Early Start	Early Finish
SUB S.D/ PROD DATA. FO	37 days	Mon 7/16/12	Tue 9/4/12
A/E REVIEW S/D PROD DATE TURF	10 days	Mon 9/10/12	Fri 9/21/12
FAB & DEL TURF	48 days	Mon 9/24/12	Wed 11/28/12
TURF STRING LINES & CHECK COMPACTION 1-4	1 day	Thu 11/22/12	Thu 11/22/12
INSTALL TURF PANELS 1-4 (MAKE IT GREEN)	5 days	Mon 12/3/12	Fri 12/7/12
INSTALL TURF PANELS 5 - 8 (MAKE IT GREEN)	7 days	Mon 12/10/12	Tue 12/18/12
CUT OUT& INST TURF FIELD IN -LAYS 1-8	7 days	Wed 12/19/12	Thu 12/27/12
INSTALL TURF INFILL 1-8	7 days	Mon 12/31/12	Tue 1/8/13
GLUE EDGES TO CONCRETE CURBS 1-8	3 days	Thu 1/10/13	Mon 1/14/13

Concrete Foundation and Flatwork



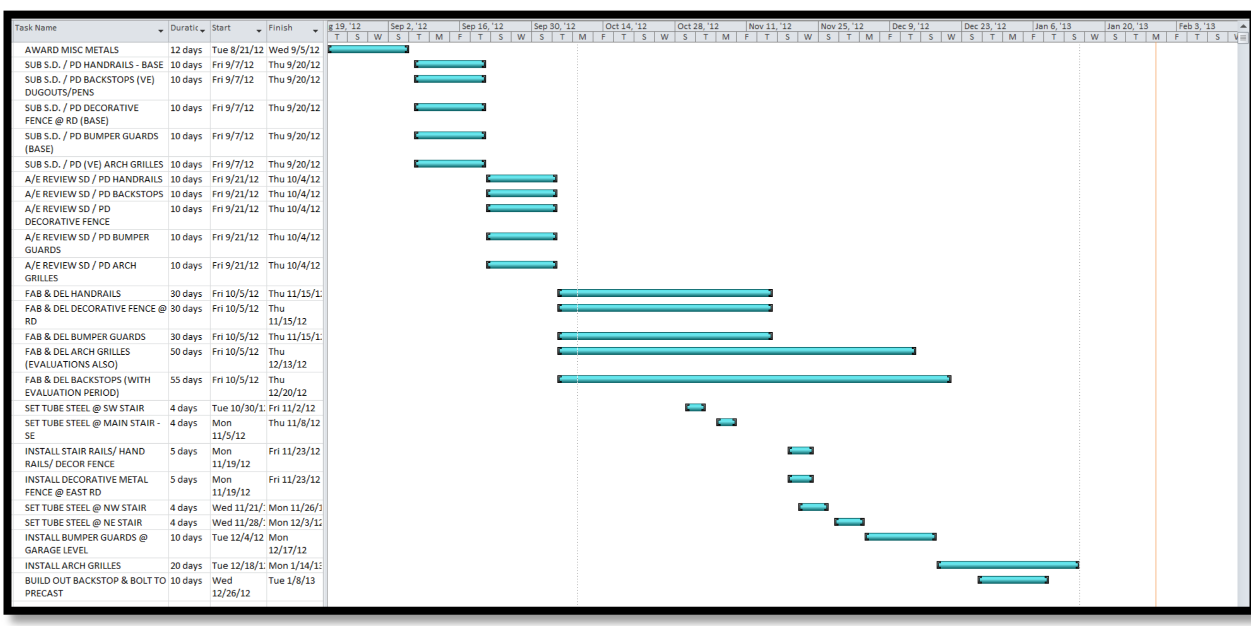
Task Name	Duration	Start	Finish
PREP & PLACE SOG @ GA	5 days	Fri 9/14/12	Thu 9/20/12
FRP PERI CONC SIDEWALKS 1-4	12 days	Wed 10/31/12	Thu 11/15/12
FRP CONC INFIELD 1-4	10 days	Thu 11/15/12	Wed 11/28/12
FRP CONCRETE ISLANDS LWR LVL - GARAGE	5 days	Thu 11/22/12	Wed 11/28/12
FRP PERI CONC SIDEWALKS @ FIELD 5 - 8	13 days	Mon 12/3/12	Wed 12/19/12

Masonry & CMU



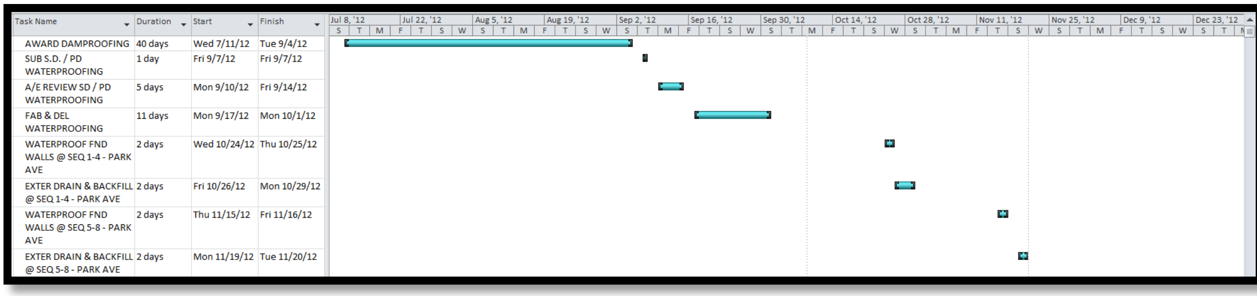
Task Name	Duration	Start	Finish
AWARD MASONRY	11 days	Thu 8/9/12	Thu 8/23/12
SUB S.D. / PD MASONRY	10 days	Fri 9/7/12	Thu 9/20/12
A/E REVIEW SD / PD MASONRY	10 days	Fri 9/21/12	Thu 10/4/12
FAB & DEL MASONRY	20 days	Fri 10/5/12	Thu 11/1/12
CMU WALLS @ GARAGE LEVEL	10 days	Fri 11/2/12	Thu 11/15/12
COMPLETE CMU WALLS @ GARAGE LEVEL	5 days	Mon 11/19/12	Fri 11/23/12

Misc. Metals



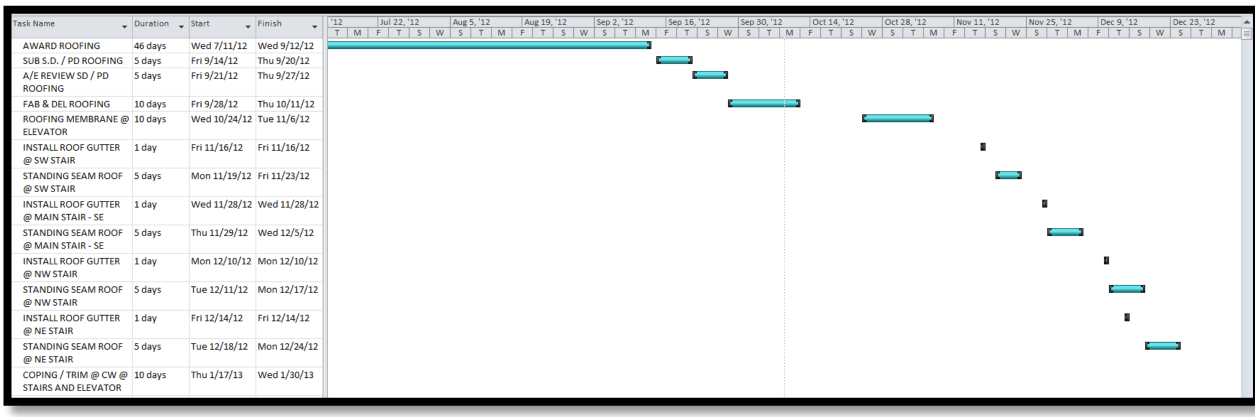
Task Name	Duratic	Start	Finish
AWARD MISC METALS	12 days	Tue 8/21/12	Wed 9/5/12
SUB S.D. / PD HANDRAILS - BASE	10 days	Fri 9/7/12	Thu 9/20/12
SUB S.D. / PD BACKSTOPS (VE) DUGOUTS/PENS	10 days	Fri 9/7/12	Thu 9/20/12
SUB S.D. / PD DECORATIVE FENCE @ RD (BASE)	10 days	Fri 9/7/12	Thu 9/20/12
SUB S.D. / PD BUMPER GUARDS (BASE)	10 days	Fri 9/7/12	Thu 9/20/12
SUB S.D. / PD (VE) ARCH GRILLES	10 days	Fri 9/7/12	Thu 9/20/12
A/E REVIEW SD / PD HANDRAILS	10 days	Fri 9/21/12	Thu 10/4/12
A/E REVIEW SD / PD BACKSTOPS	10 days	Fri 9/21/12	Thu 10/4/12
A/E REVIEW SD / PD DECORATIVE FENCE	10 days	Fri 9/21/12	Thu 10/4/12
A/E REVIEW SD / PD BUMPER GUARDS	10 days	Fri 9/21/12	Thu 10/4/12
A/E REVIEW SD / PD ARCH GRILLES	10 days	Fri 9/21/12	Thu 10/4/12
FAB & DEL HANDRAILS	30 days	Fri 10/5/12	Thu 11/15/1
FAB & DEL DECORATIVE FENCE @ RD	30 days	Fri 10/5/12	Thu 11/15/12
FAB & DEL BUMPER GUARDS	30 days	Fri 10/5/12	Thu 11/15/1
FAB & DEL ARCH GRILLES (EVALUATIONS ALSO)	50 days	Fri 10/5/12	Thu 12/13/12
FAB & DEL BACKSTOPS (WITH EVALUATION PERIOD)	55 days	Fri 10/5/12	Thu 12/20/12
SET TUBE STEEL @ SW STAIR	4 days	Tue 10/30/1	Fri 11/2/12
SET TUBE STEEL @ MAIN STAIR - SE	4 days	Mon 11/5/12	Thu 11/8/12
INSTALL STAIR RAILS/ HAND RAILS/ DECOR FENCE	5 days	Mon 11/19/12	Fri 11/23/12
INSTALL DECORATIVE METAL FENCE @ EAST RD	5 days	Mon 11/19/12	Fri 11/23/12
SET TUBE STEEL @ NW STAIR	4 days	Wed 11/21/	Mon 11/26/1
SET TUBE STEEL @ NE STAIR	4 days	Wed 11/28/	Mon 12/3/1
INSTALL BUMPER GUARDS @ GARAGE LEVEL	10 days	Tue 12/4/12	Mon 12/17/12
INSTALL ARCH GRILLES	20 days	Tue 12/18/1	Mon 1/14/1
BUILD OUT BACKSTOP & BOLT TO PRECAST	10 days	Wed 12/26/12	Tue 1/8/13

Water & Damp Proofing



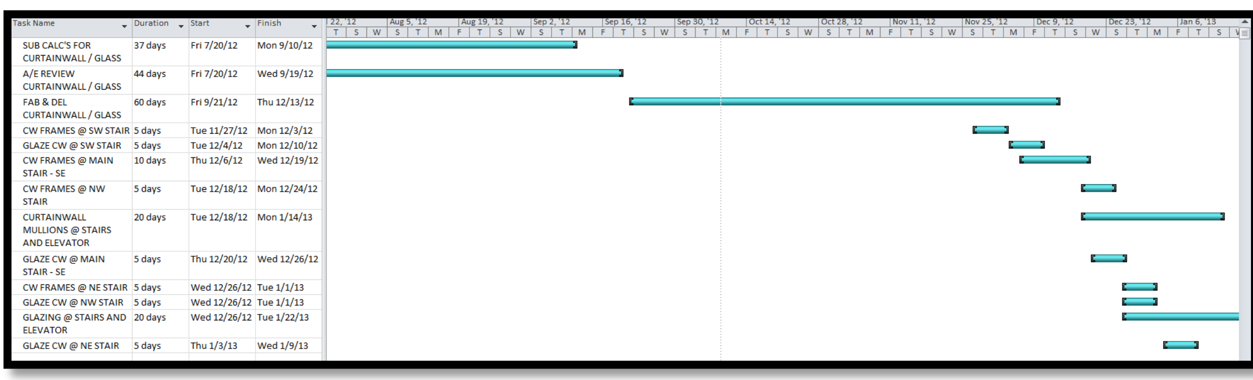
Task Name	Duration	Start	Finish
AWARD DAMPPROOFING	40 days	Wed 7/11/12	Tue 9/4/12
SUB S.D. / PD WATERPROOFING	1 day	Fri 9/7/12	Fri 9/7/12
A/E REVIEW SD / PD WATERPROOFING	5 days	Mon 9/10/12	Fri 9/14/12
FAB & DEL WATERPROOFING	11 days	Mon 9/17/12	Mon 10/1/12
WATERPROOF FND WALLS @ SEQ 1-4 - PARK AVE	2 days	Wed 10/24/12	Thu 10/25/12
EXTER DRAIN & BACKFILL @ SEQ 1-4 - PARK AVE	2 days	Fri 10/26/12	Mon 10/29/12
WATERPROOF FND WALLS @ SEQ 5-8 - PARK AVE	2 days	Thu 11/15/12	Fri 11/16/12
EXTER DRAIN & BACKFILL @ SEQ 5-8 - PARK AVE	2 days	Mon 11/19/12	Tue 11/20/12

Roofing



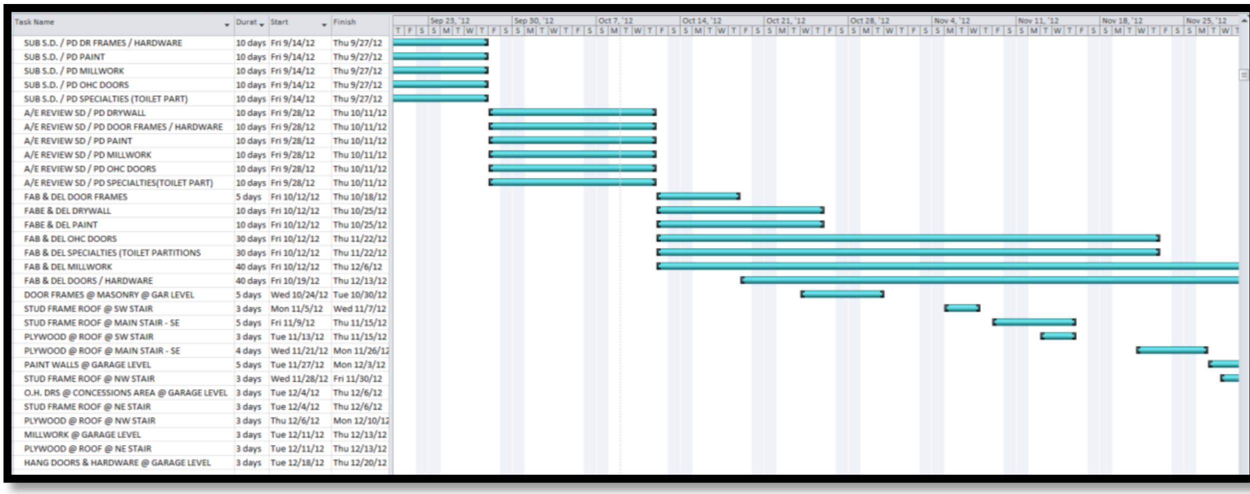
Task Name	Duration	Start	Finish
AWARD ROOFING	46 days	Wed 7/11/12	Wed 9/12/12
SUB S.D. / PD ROOFING	5 days	Fri 9/14/12	Thu 9/20/12
A/E REVIEW SD / PD ROOFING	5 days	Fri 9/21/12	Thu 9/27/12
FAB & DEL ROOFING	10 days	Fri 9/28/12	Thu 10/11/12
ROOFING MEMBRANE @ ELEVATOR	10 days	Wed 10/24/12	Tue 11/6/12
INSTALL ROOF GUTTER @ SW STAIR	1 day	Fri 11/16/12	Fri 11/16/12
STANDING SEAM ROOF @ SW STAIR	5 days	Mon 11/19/12	Fri 11/23/12
INSTALL ROOF GUTTER @ MAIN STAIR - SE	1 day	Wed 11/28/12	Wed 11/28/12
STANDING SEAM ROOF @ MAIN STAIR - SE	5 days	Thu 11/29/12	Wed 12/5/12
INSTALL ROOF GUTTER @ NW STAIR	1 day	Mon 12/10/12	Mon 12/10/12
STANDING SEAM ROOF @ NW STAIR	5 days	Tue 12/11/12	Mon 12/17/12
INSTALL ROOF GUTTER @ NE STAIR	1 day	Fri 12/14/12	Fri 12/14/12
STANDING SEAM ROOF @ NE STAIR	5 days	Tue 12/18/12	Mon 12/24/12
COPING / TRIM @ CW @ STAIRS AND ELEVATOR	10 days	Thu 1/17/13	Wed 1/30/13

Exterior Window & Glazing



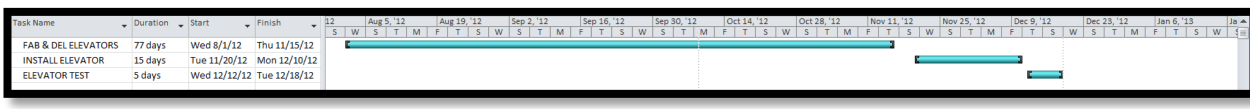
Task Name	Duration	Start	Finish
SUB CALC'S FOR CURTAINWALL / GLASS	37 days	Fri 7/20/12	Mon 9/10/12
A/E REVIEW CURTAINWALL / GLASS	44 days	Fri 7/20/12	Wed 9/19/12
FAB & DEL CURTAINWALL / GLASS	60 days	Fri 9/21/12	Thu 12/13/12
CW FRAMES @ SW STAIR	5 days	Tue 11/27/12	Mon 12/3/12
GLAZE CW @ SW STAIR	5 days	Tue 12/4/12	Mon 12/10/12
CW FRAMES @ MAIN STAIR - SE	10 days	Thu 12/6/12	Wed 12/19/12
CW FRAMES @ NW STAIR	5 days	Tue 12/18/12	Mon 12/24/12
CURTAINWALL MULLIONS @ STAIRS AND ELEVATOR	20 days	Tue 12/18/12	Mon 1/14/13
GLAZE CW @ MAIN STAIR - SE	5 days	Thu 12/20/12	Wed 12/26/12
CW FRAMES @ NE STAIR	5 days	Wed 12/26/12	Tue 1/1/13
GLAZE CW @ NW STAIR	5 days	Wed 12/26/12	Tue 1/1/13
GLAZING @ STAIRS AND ELEVATOR	20 days	Wed 12/26/12	Tue 1/22/13
GLAZE CW @ NE STAIR	5 days	Thu 1/3/13	Wed 1/9/13

General Trades



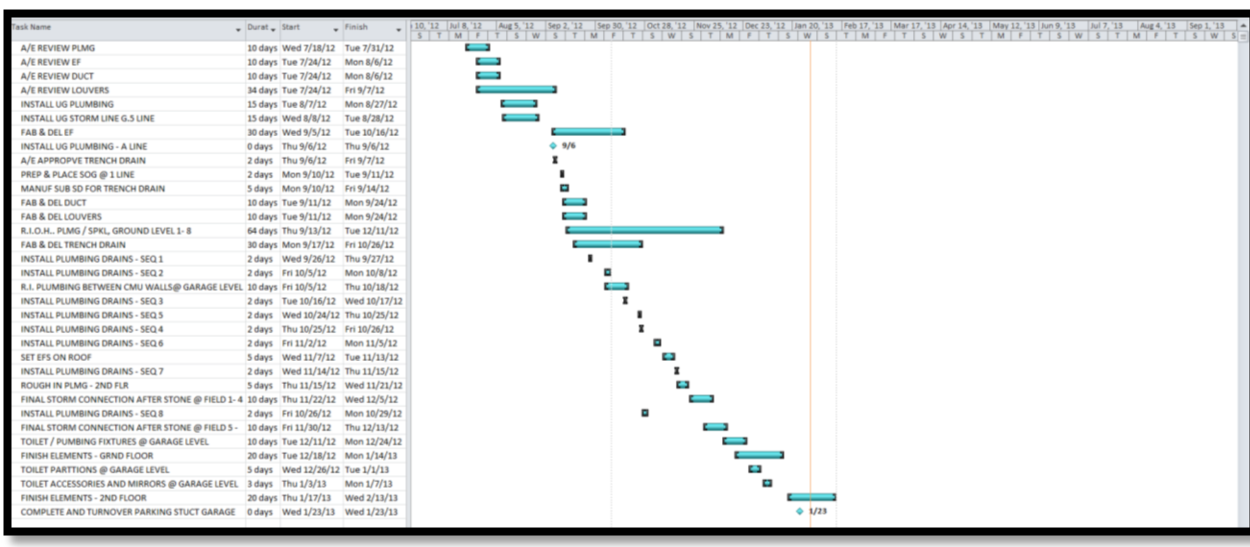
Task Name	Durat	Start	Finish
SUB S.D. / PD DR FRAMES / HARDWARE	10 days	Fri 9/14/12	Thu 9/27/12
SUB S.D. / PD PAINT	10 days	Fri 9/14/12	Thu 9/27/12
SUB S.D. / PD MILLWORK	10 days	Fri 9/14/12	Thu 9/27/12
SUB S.D. / PD OHC DOORS	10 days	Fri 9/14/12	Thu 9/27/12
SUB S.D. / PD SPECIALTIES (TOILET PART)	10 days	Fri 9/14/12	Thu 9/27/12
A/E REVIEW SD / PD DRYWALL	10 days	Fri 9/28/12	Thu 10/11/12
A/E REVIEW SD / PD DOOR FRAMES / HARDWARE	10 days	Fri 9/28/12	Thu 10/11/12
A/E REVIEW SD / PD PAINT	10 days	Fri 9/28/12	Thu 10/11/12
A/E REVIEW SD / PD MILLWORK	10 days	Fri 9/28/12	Thu 10/11/12
A/E REVIEW SD / PD OHC DOORS	10 days	Fri 9/28/12	Thu 10/11/12
A/E REVIEW SD / PD SPECIALTIES(TOILET PART)	10 days	Fri 9/28/12	Thu 10/11/12
FAB & DEL DOOR FRAMES	5 days	Fri 10/12/12	Thu 10/18/12
FABE & DEL DRYWALL	10 days	Fri 10/12/12	Thu 10/25/12
FABE & DEL PAINT	10 days	Fri 10/12/12	Thu 10/25/12
FAB & DEL OHC DOORS	30 days	Fri 10/12/12	Thu 11/22/12
FAB & DEL SPECIALTIES (TOILET PARTITIONS	30 days	Fri 10/12/12	Thu 11/22/12
FAB & DEL MILLWORK	40 days	Fri 10/12/12	Thu 12/6/12
FAB & DEL DOORS / HARDWARE	40 days	Fri 10/19/12	Thu 12/13/12
DOOR FRAMES @ MASONRY @ GAR LEVEL	5 days	Wed 10/24/12	Tue 10/30/12
STUD FRAME ROOF @ SW STAIR	3 days	Mon 11/5/12	Wed 11/7/12
STUD FRAME ROOF @ MAIN STAIR - SE	5 days	Fri 11/9/12	Thu 11/15/12
PLYWOOD @ ROOF @ SW STAIR	3 days	Tue 11/13/12	Thu 11/15/12
PLYWOOD @ ROOF @ MAIN STAIR - SE	4 days	Wed 11/21/12	Mon 11/26/12
PAINT WALLS @ GARAGE LEVEL	5 days	Tue 11/27/12	Mon 12/3/12
STUD FRAME ROOF @ NW STAIR	3 days	Wed 11/28/12	Fri 11/30/12
O.H. DRS @ CONCESSIONS AREA @ GARAGE LEVEL	3 days	Tue 12/4/12	Thu 12/6/12
STUD FRAME ROOF @ NE STAIR	3 days	Tue 12/4/12	Thu 12/6/12
PLYWOOD @ ROOF @ NW STAIR	3 days	Thu 12/6/12	Mon 12/10/12
MILLWORK @ GARAGE LEVEL	3 days	Tue 12/11/12	Thu 12/13/12
PLYWOOD @ ROOF @ NE STAIR	3 days	Tue 12/11/12	Thu 12/13/12
HANG DOORS & HARDWARE @ GARAGE LEVEL	3 days	Tue 12/18/12	Thu 12/20/12

Elevators



Task Name	Duration	Start	Finish
FAB & DEL ELEVATORS	77 days	Wed 8/1/12	Thu 11/15/12
INSTALL ELEVATOR	15 days	Tue 11/20/12	Mon 12/10/12
ELEVATOR TEST	5 days	Wed 12/12/12	Tue 12/18/12

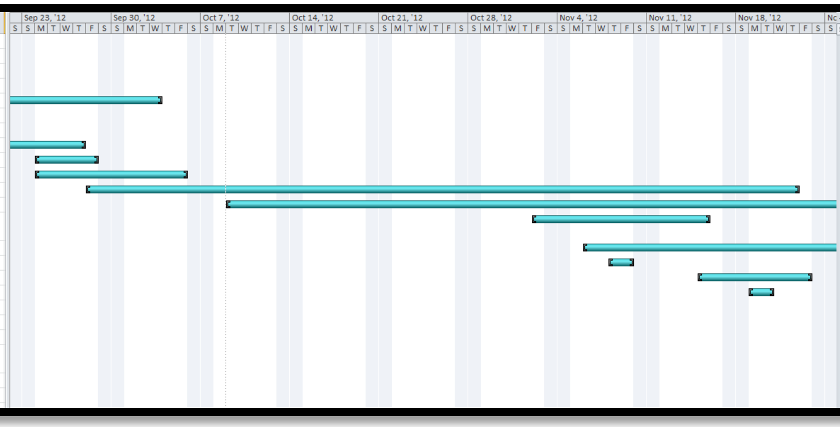
Plumbing



Task Name	Durat	Start	Finish
A/E REVIEW PLMG	10 days	Wed 7/18/12	Tue 7/31/12
A/E REVIEW EF	10 days	Tue 7/24/12	Mon 8/6/12
A/E REVIEW DUCT	10 days	Tue 7/24/12	Mon 8/6/12
A/E REVIEW LOUVERS	34 days	Tue 7/24/12	Fri 9/7/12
INSTALL UG PLUMBING	15 days	Tue 8/7/12	Mon 8/27/12
INSTALL UG STORM LINE G.5 LINE	15 days	Wed 8/8/12	Tue 8/28/12
FAB & DEL EF	30 days	Wed 9/5/12	Tue 10/16/12
INSTALL UG PLUMBING - A LINE	0 days	Thu 9/6/12	Thu 9/6/12
A/E APPROPVE TRENCH DRAIN	2 days	Thu 9/6/12	Fri 9/7/12
PREP & PLACE SOG @ 1 LINE	2 days	Mon 9/10/12	Tue 9/11/12
MANUF SUB SD FOR TRENCH DRAIN	5 days	Mon 9/10/12	Fri 9/14/12
FAB & DEL DUCT	10 days	Tue 9/11/12	Mon 9/24/12
FAB & DEL LOUVERS	10 days	Tue 9/11/12	Mon 9/24/12
R.I.O.H.. PLMG / SPKL, GROUND LEVEL 1- 8	64 days	Thu 9/13/12	Tue 12/11/12
FAB & DEL TRENCH DRAIN	30 days	Mon 9/17/12	Fri 10/26/12
INSTALL PLUMBING DRAINS - SEQ 1	2 days	Wed 9/26/12	Thu 9/27/12
INSTALL PLUMBING DRAINS - SEQ 2	2 days	Fri 10/5/12	Mon 10/8/12
R.I. PLUMBING BETWEEN CMU WALLS@ GARAGE LEVEL	10 days	Fri 10/5/12	Thu 10/18/12
INSTALL PLUMBING DRAINS - SEQ 3	2 days	Tue 10/16/12	Wed 10/17/12
INSTALL PLUMBING DRAINS - SEQ 5	2 days	Wed 10/24/12	Thu 10/25/12
INSTALL PLUMBING DRAINS - SEQ 4	2 days	Thu 10/25/12	Fri 10/26/12
INSTALL PLUMBING DRAINS - SEQ 6	2 days	Fri 11/2/12	Mon 11/5/12
SET EFS ON ROOF	5 days	Wed 11/7/12	Tue 11/13/12
INSTALL PLUMBING DRAINS - SEQ 7	2 days	Wed 11/14/12	Thu 11/15/12
ROUGH IN PLMG - 2ND FLR	5 days	Thu 11/15/12	Wed 11/21/12
FINAL STORM CONNECTION AFTER STONE @ FIELD 1- 4	10 days	Thu 11/22/12	Wed 12/5/12
INSTALL PLUMBING DRAINS - SEQ 8	2 days	Fri 10/26/12	Mon 10/29/12
FINAL STORM CONNECTION AFTER STONE @ FIELD 5 -	10 days	Fri 11/30/12	Thu 12/13/12
TOILET / PUMBING FIXTURES @ GARAGE LEVEL	10 days	Tue 12/11/12	Mon 12/24/12
FINISH ELEMENTS - GRND FLOOR	20 days	Tue 12/18/12	Mon 1/14/13
TOILET PARTTIONS @ GARAGE LEVEL	5 days	Wed 12/26/12	Tue 1/1/13
TOILET ACCESSORIES AND MIRRORS @ GARAGE LEVEL	3 days	Thu 1/3/13	Mon 1/7/13
FINISH ELEMENTS - 2ND FLOOR	20 days	Thu 1/17/13	Wed 2/13/13
COMPLETE AND TURNOVER PARKING STUCT GARAGE	0 days	Wed 1/23/13	Wed 1/23/13

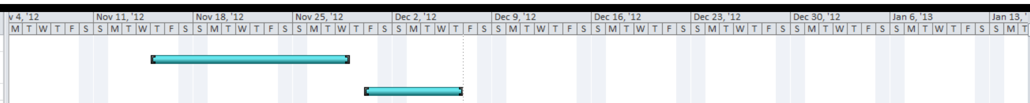
Electrical

Task Name	Duration	Start	Finish
SUB P.D. FOR LIGHTING	5 days	Fri 7/13/12	Thu 7/19/12
INSTALL UG ELECTRICAL	26 days	Tue 8/7/12	Tue 9/11/12
SUB P.D. FOR GARAGE GATE	5 days	Mon 8/27/12	Fri 8/31/12
WPI DECISWION ON TYPE LIGHTS	5 days	Thu 9/6/12	Wed 9/12/12
FAB & DEL ELECTRIC HEAT	20 days	Thu 9/6/12	Wed 10/3/12
A/E REVIEW PD GARAGE GATES	10 days	Mon 9/10/12	Fri 9/21/12
INSTALL UG ELECTRIC G.5 LINE	2 days	Fri 9/14/12	Mon 9/17/12
A/E REVIEW PD LIGHTING	10 days	Fri 9/14/12	Thu 9/27/12
FAB & DEL GARAGE GATES ANCHOR BOLTS	5 days	Mon 9/24/12	Fri 9/28/12
FAB & DEL GARAGE GATES	10 days	Mon 9/24/12	Fri 10/5/12
FAB & DEL LIGHTING	40 days	Fri 9/28/12	Thu 11/22/12
R.I.O.H. LIGHTING / FA GROUND LEVELSEQ 1-4	40 days	Tue 10/9/12	Mon 12/3/12
R.I.ELECTRIC @ MASONRY WALLS@ GARAGE LEVEL	10 days	Fri 11/2/12	Thu 11/15/12
R.I.O.H. LIGHTING / FA GROUND LEVELSEQ 5-8	40 days	Tue 11/6/12	Mon 12/31/12
R.I.ELECTRIC @ ROOF LVL @ SW STAIR	2 days	Thu 11/8/12	Fri 11/9/12
ROUGH IN LIGHTING AND F.A. - 2ND FLR	7 days	Thu 11/15/12	Fri 11/23/12
R.I.ELECTRIC @ ROOF LVL @ MAIN STAIR - SE	2 days	Mon 11/19/12	Tue 11/20/12
LIGHTING GRND FLR SEQ 1-4	15 days	Tue 11/27/12	Mon 12/17/12
INSTALL TRAFFIC GATES LWR LVL - GARAGE	3 days	Fri 11/30/12	Tue 12/4/12
R.I.ELECTRIC @ ROOF LVL @ NW STAIR	2 days	Mon 12/3/12	Tue 12/4/12
INSTALL LIGHTING CMU AREA @ GARAGE LEVEL	5 days	Tue 12/4/12	Mon 12/10/12
R.I.ELECTRIC @ ROOF LVL @ NE STAIR	2 days	Fri 12/7/12	Mon 12/10/12
LIGHTING GRND FLR SEQ 5-8	15 days	Thu 12/13/12	Wed 1/2/13



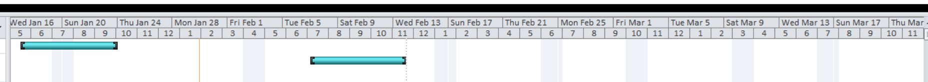
Sports Lighting

Task Name	Duration	Start	Finish
FAB & DEL SPORTS LIGHT	27 days	Mon 8/6/12	Tue 9/11/12
INSTALL FIELD LIGHT POLE BASES	10 days	Thu 11/15/12	Wed 11/28/12
TERMINATE FIELD LIGHTS	5 days	Fri 11/30/12	Thu 12/6/12



Project Milestones

Task Name	Duration	Start	Finish
PUNCHLIST & TEST	5 days	Thu 1/17/13	Wed 1/23/13
PUNCHLIST & COMPLETE PLAYING FIELD	5 days	Thu 2/7/13	Wed 2/13/13



Appendix C: List of Acronyms

AEC - Architectural, Engineering and Construction

BAC – Budget at Completion

BIM – Building Information Modeling

CPI – Cost Performance Index

CV – Cost Variance

EAC – Estimate at Completion

ETC – Estimate to Complete

EVA – Earned Value Analysis

GBC – Gilbane Building Company

GMP – Guaranteed Maximum Price

SMMA - Symmes Maini & McKee Associates

SPI – Schedule Performance Index

SV - Scheduled Variance

WPI - Worcester Polytechnic Institute

Appendix D: Interview with Lyndsy Seiferth

Date: September 12, 2012. 1:30 PM
Location: Onsite Gilbane Office for Parking Garage at WPI
Company: Gilbane Building Company (Design Build and Construction Manager at Risk)
Interviewee: Lyndsy Seiferth, Project Engineer
Interviewer: Amy Paula

Was the parking garage with the athletic top always the main plan or did you speak about any alternative projects to be done with the field, or alleviate parking?

This project was not typical project. Normally, the owner would hire an architect to design the project and the construction management company would be brought on later to bid the project. WPI Brought Gilbane on to this project early on. This project has been in the conceptual design process for the past 2-3 years. There were several options including a two story parking garage and an underground parking garage. Overall the one story, above grade garage seemed to be the best option.

How much of the architectural and structural designs were completed when this project was out to bid?

Normally it would depend on the contract. For this project, a lot of educated assumptions were made based on previous project and other relevant factors. When this project was estimates, roughly 80% of the design was completed.

What is then general process of bidding a design build project, since you don't have definite designs yet, how are you able to give a bid?

Generally, the architect has most of the designs completed from the bid process. Again, this process was different because Gilbane was brought on the project so early on. But we were able to develop an estimate based on assumptions and previous experience.

What are your main responsibilities for this project?

The project engineer typically handles submittals, RFI's (Request for information), buy outs, daily changes in the job. Overall the project engineer is involved in depth with all aspects of the project.

How does that differ from the project manager?

The project manager deals with more general big picture aspects of the construction project. This includes developing and tracking the schedule, as well as presenting major changes in the project to the owner. The project manager runs the weekly owner meetings which are meetings that conveys project updates and discusses changes and decisions that need to be address in the project.

When you accept bids from the subcontractors, do they provide any type of a rough schedule to complete their work?

Yes. Since Gilbane is such a large company, all subcontractor bids are submitted electronically. The subcontractors to bid the project typically have a good standing relationship with Gilbane and have worked with Gilbane in the past. Certain sections of the online data base allow subcontractors to submit prequalification's, projected schedules and questions they may have on the project. The low 2-3 different subcontractors are brought in for a scope review and the subcontractor is picked from that.

This project is on an extremely tight schedule. If this project falls behind schedule due to weather or other unforeseen circumstances, what are effective approaches to making up for lost time?

When the subcontractors bid this project, we requested additional information for working on Saturdays and working longer days. We have been trying to do as much as possible to make sure this job is on schedule and it has been so far. We also have been looking at the critical path trades and looking at which trades can be held off to a later date.

The parking garage is requested to be completed for the first week of January, is there a separate completion date for the athletic rooftop field?

Not yet, we still plan on completing the entire project on time. If we have a mild winter similar to last year, we shouldn't have any issues hitting our completion date.

Were there any changes in this project that caused the project to be ahead of schedule?

Yes. The height of the drainage layers beneath the athletic field, including the layers of filter fabric and crushed stone, were decreased, so that will shorten our schedule for that section of the project. Also, the precast erection subcontractor has been very on board with this project and is ahead of schedule.

What do you think is the biggest construction challenge for this project?

The main constraints and challenges with this project is depending on the weather for our short time line.

What do you think is the biggest project management challenge for this project?

Nothing major should affect the schedule at this point. All of the trades are away of the tight schedule. We have and are cooperative about getting activities done in a timely manner.

Appendix E: Foundation Design Calculations

Load Calculations

Live Load	100 psf			Load Combinations	
Dead Loads	174.03 psf			U=1.4D	243.64 psf
Double tee	62.62 psf			U=1.2D+1.6L+0.5S	385.34 psf
Gravel	74.37 psf			U=1.2D+1.6W+0.5L+0.5S	292.94 psf
girders	37.04 psf			U=1.2D+1.6S+(0.5L or 0.8W)	311.64 psf
				U=0.9D+(1.6W or 1.0E)	287.34 psf
Snow Load	33 psf				
Seismic load	130.2 psf			Governing Load Combination	
Wind Load	11 psf			385.34 psf	

Appendix F: Column Loads

Column	Side (x) ft	Side (y) ft	Area (ft2)	Total Load on Foundation (kips)
A1	30.70	21.50	660.05	254.34
A2	59.70	21.50	1283.55	494.60
A3	58.00	21.50	1247.00	480.52
A4	58.00	21.50	1247.00	480.52
A5	58.00	21.50	1247.00	480.52
A6	58.00	21.50	1247.00	480.52
A7	58.00	21.50	1247.00	480.52
A8	58.00	21.50	1247.00	480.52
A9	58.00	21.50	1247.00	480.52
A10	58.00	21.50	1247.00	480.52
A11	57.50	21.50	1236.25	476.38
A12	28.50	21.50	612.75	236.12
B1	30.70	39.50	1212.65	467.28
B2	59.70	39.50	2358.15	908.69
B3	58.00	39.50	2291.00	882.81
B4	58.00	39.50	2291.00	882.81
B5	58.00	39.50	2291.00	882.81
B6	58.00	39.50	2291.00	882.81
B7	58.00	39.50	2291.00	882.81
B8	58.00	39.50	2291.00	882.81
B9	58.00	39.50	2291.00	882.81
B10	58.00	39.50	2291.00	882.81
B11	57.50	39.50	2271.25	875.20
B12	28.50	39.50	1125.75	433.80
C1	30.70	36.00	1105.20	425.88
C2	59.70	36.00	2149.20	828.17
C3	58.00	36.00	2088.00	804.59
C4	58.00	36.00	2088.00	804.59
C5	58.00	36.00	2088.00	804.59

C6	58.00	36.00	2088.00	804.59
C7	58.00	36.00	2088.00	804.59
C8	58.00	36.00	2088.00	804.59
C9	58.00	36.00	2088.00	804.59
C10	58.00	36.00	2088.00	804.59
C11	57.50	36.00	2070.00	797.65
C12	28.50	36.00	1026.00	395.36
D1	30.70	36.00	1105.20	425.88
D2	59.70	36.00	2149.20	828.17
D3	58.00	36.00	2088.00	804.59
D4	58.00	36.00	2088.00	804.59
D5	58.00	36.00	2088.00	804.59
D6	58.00	36.00	2088.00	804.59
D7	58.00	36.00	2088.00	804.59
D8	58.00	36.00	2088.00	804.59
D9	58.00	36.00	2088.00	804.59
D10	58.00	36.00	2088.00	804.59
D11	57.50	36.00	2070.00	797.65
D12	28.50	36.00	1026.00	395.36
E1	30.70	36.00	1105.20	425.88
E2	59.70	36.00	2149.20	828.17
E3	58.00	36.00	2088.00	804.59
E4	58.00	36.00	2088.00	804.59
E5	58.00	36.00	2088.00	804.59
E6	58.00	36.00	2088.00	804.59
E7	58.00	36.00	2088.00	804.59
E8	58.00	36.00	2088.00	804.59
E9	58.00	36.00	2088.00	804.59
E10	58.00	36.00	2088.00	804.59
E11	57.50	36.00	2070.00	797.65

E12	28.50	36.00	1026.00	395.36
F1	30.70	36.00	1105.20	425.88
F2	59.70	36.00	2149.20	828.17
F3	58.00	36.00	2088.00	804.59
F4	58.00	36.00	2088.00	804.59
F5	58.00	36.00	2088.00	804.59
F6	58.00	36.00	2088.00	804.59
F7	58.00	36.00	2088.00	804.59
F8	58.00	36.00	2088.00	804.59
F9	58.00	36.00	2088.00	804.59
F10	58.00	36.00	2088.00	804.59
F11	57.50	36.00	2070.00	797.65
F12	28.50	36.00	1026.00	395.36
G1	30.70	39.00	1197.30	461.37
G2	59.70	39.00	2328.30	897.19
G3	58.00	39.00	2262.00	871.64
G4	58.00	39.00	2262.00	871.64
G5	58.00	39.00	2262.00	871.64
G6	58.00	39.00	2262.00	871.64
G7	58.00	39.00	2262.00	871.64
G8	58.00	39.00	2262.00	871.64
G9	58.00	39.00	2262.00	871.64
G10	58.00	39.00	2262.00	871.64
G11	57.50	39.00	2242.50	864.12
G12	28.50	39.00	1111.50	428.31
H1	30.70	21.00	644.70	248.43
H2	59.70	21.00	1253.70	483.10
H3	58.00	21.00	1218.00	469.34
H4	58.00	21.00	1218.00	469.34
H5	58.00	21.00	1218.00	469.34
H6	58.00	21.00	1218.00	469.34
H7	58.00	21.00	1218.00	469.34
H8	58.00	21.00	1218.00	469.34
H9	58.00	21.00	1218.00	469.34
H10	58.00	21.00	1218.00	469.34
H11	57.50	21.00	1207.50	465.30
H12	28.50	21.00	598.50	230.63

Appendix G: Shallow Foundation

From Bearing Capacity Chart	
Size based on 1.25" settlement	
15ft	
10.3ft	
6.8ft	

Interior Shallow Foundation	Exterior Shallow Foundation	Corner Shallow Foundation
B=180in	B=124in	B=82in
T=30in	T=30in	T=30in
d=26in	d=26in	d=26in
b=24in	b=24in	b=24in
Pu=908K	Pu=480k	Pu=255k
#8 bars	#8 bars	#8 bars
l=78in	l=50in	l=29in
Muc=15,345,200in-lb	Muc=4,838,709.67 in-lb	Muc=1,307,352.4 in-lb
As=11.17 in2	As=3.48 in2	As=0.94 in2
Asmin=8.42 in2	Asmin=5.8 in2	Asmin=3.84 in2
15 #8 bars	8 #8 bars	5 #8 bars
12in spacing	15.5in spacing	16.4in spacing

Shallow foundation Calcs

$V_u \leq v_c$

Shear stress (v_u), concrete (v_c)

$n = \frac{B_{footing} - B_{column}}{2}$

$v_u = \frac{V_u}{\phi B d}$

$V_u = q_u B (n - d)$

$v_c = 0.53\sqrt{F_c'}$

$M_{uc} = \frac{P_u n^2}{2B}$

$A_S = \frac{F_c' b}{1.176 F_y}\left(d - \sqrt{d^2 - \frac{2.353 M_u}{\phi F_c' b}}\right)$

Interior shallow foundation   180"×180"

T = 30in $d = T - 3in - d_b$

#8 bars $d = 30 - 3 - 1$

$d = 26 in$

$b = 24in$

$P_u = 908$

$I = \frac{B - C}{2} = \frac{180 - 24}{2} = 78 in$

Flexural Stress

$M_{uc} = \frac{P_u I^2}{2B} = \frac{908^{k}(78)^2}{2(180)} = 15,345,200 \text{ in-lb}$

Area of Steel:

$A_S = \frac{F_c' b}{1.176 F_y} \cdot \left(d - \sqrt{d^2 - \frac{2.353 M_{uc}}{\phi F_c' b}}\right)$

$\frac{4000(180)}{1.176(60,000)} \cdot \left(26 - \sqrt{26^2 - \frac{2.353 \cdot 15345200}{0.90(4000)(180)}}\right)$

$= 11.17 in^2$

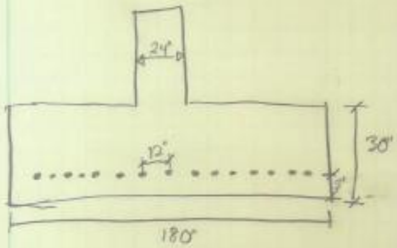
$\#8 = 0.79\ in^2$

15 #8 bars both directions

12in spacing

$A_{s_{min}} = 0.018\,(26)(180)$

$= 8.42\ in^2$ $\qquad 11.85\ in^2 > 9.72\ in^2$ ✓



Exterior Shallow Foundation 124"×124"

T=30
d=26in
#8 bars
B=124
$P_u = 480K$
b=24in

$$I = \frac{124-24}{2} = 50\ in$$

$$M_{uc} = \frac{480{,}000\,(50)^2}{2(124)} = 4{,}838{,}709.67\ in\text{-}lb$$

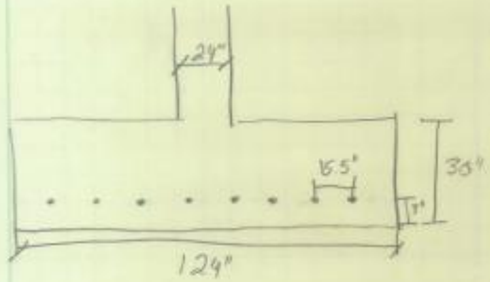
$$A_s = \frac{F'_c\ b}{1.176\ F_y}\left(d - \sqrt{d^2 - \frac{2.353\,M_{uc}}{\phi\,F'_c\,b}}\right)$$

$$= \frac{4000\,(124)}{1.176\,(60000)} \cdot \left(26 - \sqrt{26^2 - \frac{2.353\,(4838709.67)}{0.9\,(4000)\,(124)}}\right)$$

$$= 3.48\ in^2$$

$A_{s_{min}} = 0.018\,(26)(124) = 5.8\ in^2$ ←

8 #8 bars. 15.5in spacing
both directions



<u>Corner Shallow Foundation</u> 82in × 82in

$T = 30$
$d = 26$
#8 bars
$B = 82in$
$P_u = 255k$
$b = 24in$

$$I = \frac{82-24}{2} = 29in$$

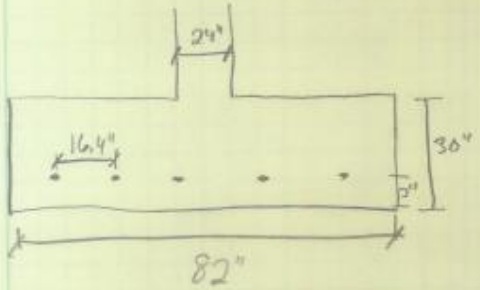
$$M_{uc} = \frac{255{,}000\,(29)^2}{2(82)} = 1307652.4 \text{ in-lb}$$

$$A_s = \frac{4000\,(82)}{1.176\,(60{,}000)}\left(26 - \sqrt{26^2 - \frac{2.353\,(1307652.4)}{(.9)(4000)(82)}}\right)$$

$$= 0.94 in$$

$$A_{s\,min} = 0.0018\,(26)(82) = \underline{3.84 in^2}$$

5 #8 bars both directions   16.4 in spacing



Appendix H: Deep Foundation

Layer I-Top Soil
1ft
K=0.5
57.5 PSF
Fs=34.5 lb/ft2

Layer II-Compact Fill
9ft
K=0.5
677.5 PSF
Fs=406.5 lb/ft2

Layer III-Organics
0.5ft
K=0.5
1263.75 PSF
fs=758.25 lb/ft2

Layer IV-Dense fill
4ft
K=0.5
1547.5 PSF
fs=928.5 lb/ft2

Layer V-Glacial Till
5ft
K=0.5
2157.5 PSF
fs=1294.5 lb/ft2

Φf/Φ'=0.8
K/K0=1.5
Φ=0.45

Interior Deep Foundation
4 piles
Pu=908k
P=227k
Pult=504K
D=55 in

Settlement (in)
1.62202E-05

Exterior+Corner Deep Foundation
4 piles
Pu=480K
P=120K
Pult=267k
D=19.4 in

Settlment (in)
1.62202E-05

Deep Foundation Calcs

f_s = unit side friction resistance

Factor of Safety toe = 3, friction = 3

$$P_a = \frac{P_{ult}}{F} = \frac{P_t + P_s - W_p}{F}$$

% Passing Sieve 200

Φ = Structural resistance Factor = 0.45

Toe bearing resistance

$$q_t' = 560 (N_1)_{60} \frac{D}{B_b} \leq 5600 (N_1)_{60} \quad (14.9)$$

$$(N_1)_{60} = N_{60} \sqrt{\frac{2000}{\sigma_z'}} \quad (4.2)$$

Test Pit - 27
1' - 5.5'
% passing #200 → Compact fill
14%

Layer I - Topsoil
1ft
K = 0.5
σ_z' = 57.5 psf
$f_s = 34.5\ lb/ft^2$

Layer II - Compact Fill
9ft
K = 0.5
σ_z' = 677.5 psf
$f_s = 406.5\ lb/ft^2$

Layer III - Organics
6.5ft
K = 0.5
σ_z' = 1263.75 psf
$f_s = 758.25\ lb/ft^2$

Layer IV - Dense Fill
4ft
K = 0.5
σ_z' = 1547.5 psf
$f_s = 928.5\ lb/ft^2$

Layer V - Glacial Till
5ft
K = 0.5
σ_z' = 2157.5 psf
$f_s = 1294.5\ lb/ft^2$

$$P_a = \frac{q_t' A_t + \sum f_s A_s}{F}$$

$$\frac{\phi_f}{\phi'} = 0.8 \quad (14.4)$$

$$f_s = K_0 \sigma_z' \left(\frac{K}{K_0}\right)\left(\frac{\phi_f}{\phi'}\right)$$

$$\frac{K}{K_0} = 1.5 \quad (14.5)$$

$$K = \frac{\sigma_x'}{\sigma_z'}$$

Interior Deep Foundation

PIF
4 piles

$P_u = \frac{908\,K}{4}$

$P = 227\,K \,/\, 0.45 = 504$

$$227\,K = \frac{291602.63D + 108.4D + 11493.5D + 1191.05D + 11667.9D + 10167D}{3}$$

$q_t' = 560(39)\frac{.17}{D}$

$A_t = \left(\frac{D}{4}\right)^2 \pi =$

$A_s = \pi \cdot d \cdot h$

$$504\,K = \frac{326{,}229.85D}{3}$$

$4.6\text{ ft} = D \quad \times 12 = 55\text{ in}$

Exterior Deep Foundation + corner

PIF
4 piles

$P_u = \frac{480\,K}{4}$

$P = 120\,K \,/\, 0.45 = 266.6\,K$

$$266.6\,K = \frac{326{,}229\,D}{3}$$

$D = 2.45\text{ ft} = 29.4\text{ in}$

Appendix I: Project Proposal

The main goals of this Major Qualifying Project (MQP) includes tracking project cost and progress which will be further analyzed by an earned value analysis, creating of 3D Building Information Modeling (BIM) of the finished parking garage. Once the 3D model is created, it will be expanded into a 4D model to consider the accuracy of the proposed schedule compared to the actual schedule within monthly increments. This will be done with the use of Microsoft Project, which can be directly integrated with BIM. The next aspect of this project to consider is the use overall budget of the project which will bring the model to 5D. Comparing actual costs with estimated budgets to reflect what changes may occur throughout the project.

This MQP also focuses on how to design a cost and material efficient combination (deep and shallow) foundation for the new Worcester Polytechnic Institute parking garage with an athletic rooftop. This project is broken down over 21 school weeks. The project schedule is shown in the figure below.

D		Task Mode	Task Name	Duration	Start	Finish
1			BIM Foundations	5 days	Mon 9/17/12	Fri 9/21/12
2			BIM Parking Level	4 days	Mon 9/24/12	Thu 9/27/12
3			BIM Field	3 days	Fri 9/28/12	Tue 10/2/12
4			BIM Lockers and Misc	3 days	Thu 10/4/12	Mon 10/8/12
5			BIM Design Complete	0 days	Wed 10/10/12	Wed 10/10/12
6			Interviews	15 days	Wed 9/26/12	Tue 10/16/12
7			BIM 4D Model	8 days	Mon 10/22/12	Wed 10/31/12
8			BIM 5D Model	8 days	Thu 11/1/12	Mon 11/12/12
9			Compare Actual & Planned Construction	8 days	Tue 11/13/12	Thu 11/22/12
10			Report Revisions	10 days	Fri 11/23/12	Thu 12/6/12
11			Soil Profile	10 days	Mon 9/24/12	Fri 10/5/12
12			Loading & Bearing Calcs	15 days	Tue 10/23/12	Mon 11/12/12
13			Deep & Shallow Foundation Calcs	20 days	Mon 11/12/12	Fri 12/7/12
14			Foundation Design Complete	0 days	Wed 12/12/12	Wed 12/12/12
15			Compare Actual & Planned Foundations	15 days	Thu 1/10/13	Wed 1/30/13
16			Report Revisions	15 days	Thu 1/31/13	Wed 2/20/13

As show above, the majority of the project management side of this project was done upfront. This was done for a breakdown of time management. The construction aspects of the project are important to understand the overall big picture of the project, understanding the different roles of team members and which companies are responsible for each part of the project. The foundation design will then be completed

Appendix J: Electronic Files

BIM.rvt

FoundationCalculationsFinal.xlsx